

Chapter 4

Tall Oil Soap Recovery

by C. Douglas Foran

Introduction

What Is Tall Oil Soap?

The alkaline pulping of softwoods in the kraft process converts the resin acids and fatty acids in wood to their sodium salts. Associated with the salts are neutral or unsaponifiable compounds. The salts and unsaponifiable compounds separate from the spent cooking liquor as "black liquor soap." Wood species, dissolved solids content of the liquor, temperature, and residual effective alkalinity can influence this separation (1-3). Table 4.1 lists the composition of crude tall oil by various regions.

Table 4.1. Composition of crude tall oil

| | South-eastern U.S. | Northern U.S. & Canada | Scandinavia |
|--------------------|--------------------|------------------------|-------------|
| Acid no.* | 172 | 135 | 155 |
| Saponification no. | 172 | 166 | 142 |
| Resin acids (%) | 40 | 30 | 42 |
| Fatty acids (%) | 50 | 40 | 39 |
| Unsaps (%) | 8 | 15 | 10 |

*Number of mil equivalents of potassium hydroxide needed to neutralize one gram of crude tall oil.

The tall oil resin acids produced from the soap are mixtures of oxidized diterpene acids found in gum and wood rosins; these come from the same precursors in the tree (4). Kraft cooking results in a different distribution of components. Table 4.2 lists typical rosin compositions.

Table 4.2. Typical rosin compositions

| Components | Tall oil (%) | Gum (%) | Wood (%) |
|----------------|--------------|---------|----------|
| Pimaric | 2 | 3 | 3 |
| Palustric | 18 | 10 | 10 |
| Isopimaric | 18 | 11 | 7 |
| Abietic | 20 | 45 | 35 |
| Dehydroabietic | 4 | 8 | 20 |
| Neoabietic | 18 | 7 | 4 |

The tall oil fatty acids include oleic, linoleic, linolenic, palmitic, and stearic; of these, oleic and linoleic acids are the most common.

How Much Tall Oil Soap Is Present and Recoverable?

The quantity of tall oil soap recovered by a given mill varies according to wood species, season of the year, and wood storage practices. The quantity of tall oil available in several southeastern wood species has been determined by solvent extraction, and are presented in Table 4.3 (5).

Table 4.3 Total tall oil available by species

| Pine species | Tall oil (lb/o.d ton) |
|--------------|-----------------------|
| Longleaf | 87 |
| Slash | 83 |
| Loblolly | 71 |
| Shortleaf | 69 |
| Spruce | 62 |

Tall oil soap recovery is usually somewhat lower than what is available in the wood, due to differences in storage methods and operating practices. Crude tall oil soap recovery is regularly reported by the Pulp Chemicals Association for its member companies, most of which are located in the Southeastern United States. Table 4.4 provides the annual recovery of tall oil soap for the mills from six North American and two Scandinavian wood procurement regions.

Table 4.4 Typical tall oil yields

| Region | Tall oil (lb/o.d ton) |
|-------------------|-----------------------|
| Piedmont | 48 |
| Coastal | 52 |
| Canada | 23 |
| Southwestern U.S. | 63 |
| East of Cascades | 25 |
| West of Cascades | 15 |
| Finland | 39 |
| Sweden | 50 |

The season of the year also affects the presence, or availability, of tall oil soap in black liquor; precursors in the wood vary seasonally. The seasonal variation in tall oil soap recovery is especially pronounced in Southeastern U.S. mills due to the warmer weather that promotes

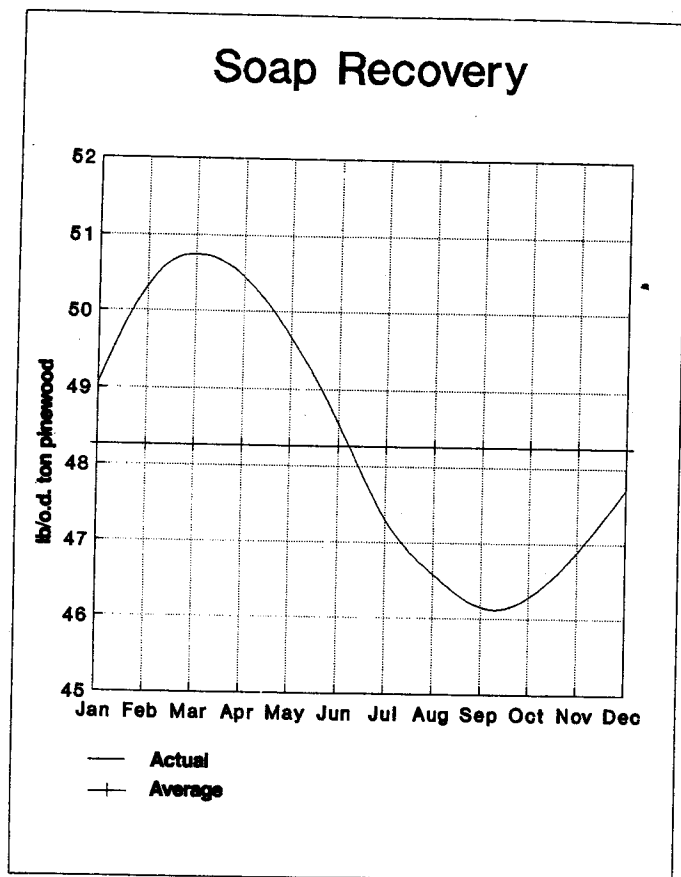


Fig. 4.1. Soap recovery seasonal variation curve

biological degradation during chip storage. Figure 4.1 represents the seasonal variation in tall oil soap recovery, based on data from two mills in the Southeastern United States.

Tall oil soap recovery is also affected by the type and duration of wood storage; loss from wood occurs rapidly during the first two months (6). This loss, which can range from 50–65% after two months of storage (Fig. 4.2) is highly dependent upon the manner in which the wood is stored. Wood stored as roundwood loses less tall oil soap than when stored as chips.

Why Should the Tall Oil Soap Be Removed?

The most important benefit of removing tall oil soap from black liquor is improved evaporator operation. Tall oil soap is also a valuable by-product of the alkaline pulping operation. In 1975, a study by Grace (7) defined the nature and extent of scaling problems in the alkaline pulping industry. More than 75% of the mills responding to the survey had experienced problems with one or more types of scales. Of these, calcium scales and soluble Na_2CO_3 - Na_2SO_4 scales were the most common. Others (8,9) have shown that soap is a significant scale component, particularly in soluble carbonate-sulfate scales in evaporators and concentrators. Mill and pilot plant studies were done to clarify the importance of soap in evaporator

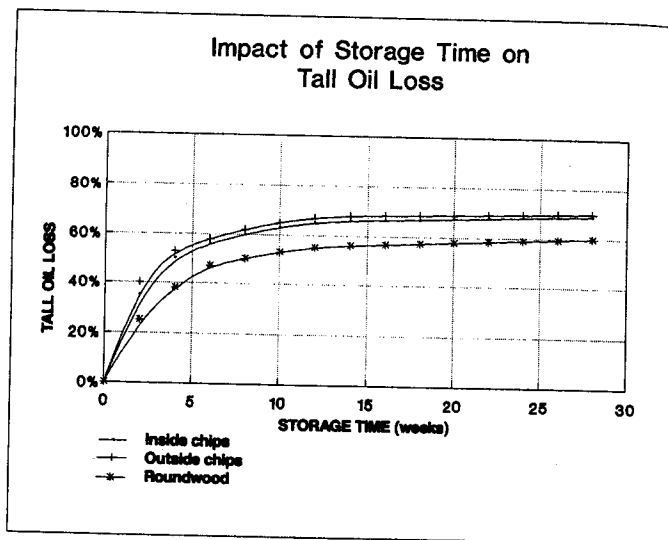


Fig. 4.2. Impact of storage time on tall oil loss

scale formation and quantify its effect on scaling rates (10). The results are represented in Fig. 4.3 and Fig. 4.4. Grace similarly found that Tall Oil soap addition to black liquor increased calcium scaling by about 30%.

In addition to its impact on evaporator scaling, soap also reduces the liquor burning capacity of steam-side limited recovery boilers (11). The burning of soap, even at low concentrations, was found to increase total reduced sulfur (TRS) emissions, and the boiler fouling rate was also increased at a given liquor firing rate. Kubes (12) has shown that there may be a connection between liquor soap content and the occurrence of blackouts in kraft recovery boilers.

Soap Removal Methods

Factors Affecting Soap Removal

Drew and Propst (1) have prepared an excellent summary of the various laboratory and mill studies affecting the recovery of tall oil soap. Most of the mills studied were in the southeastern United States. A later study (2) on Canadian mills helped to clarify some controversial effects such as the impact of hardwood liquor.

Liquor Solids and Temperature

Tall oil soap solubility is highest in weak black liquor, where it reaches a minimum between 20 and 30% black liquor solids. The minimum solubility of the tall oil soap varied somewhat from mill to mill, but was typically 7–15 lb soap/ton of liquor solids (3–8 kg soap/metric ton). The concentration of soap in unskimmed softwood black liquor varies from 70–110 lb soap/ton of liquor solids (30–50 kg soap/metric ton).

The temperature in the soap skimmer is normally fixed by the operating temperature in the effect that feeds it. With the advent of new pulping and washing processes,

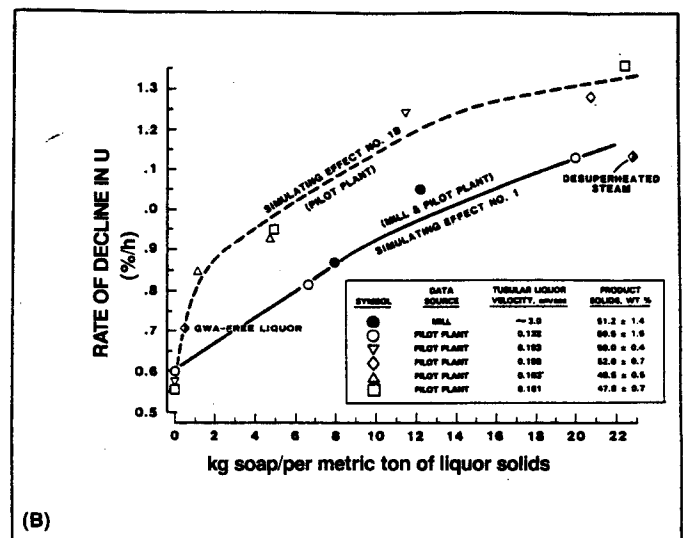
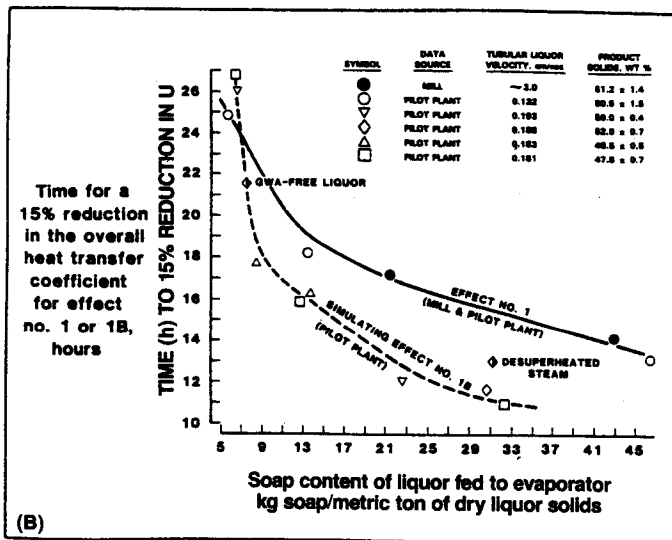
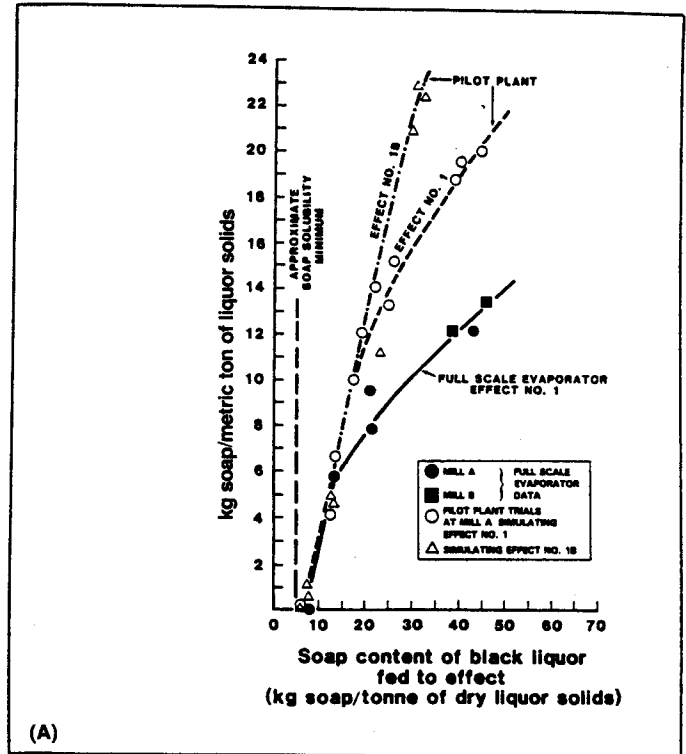
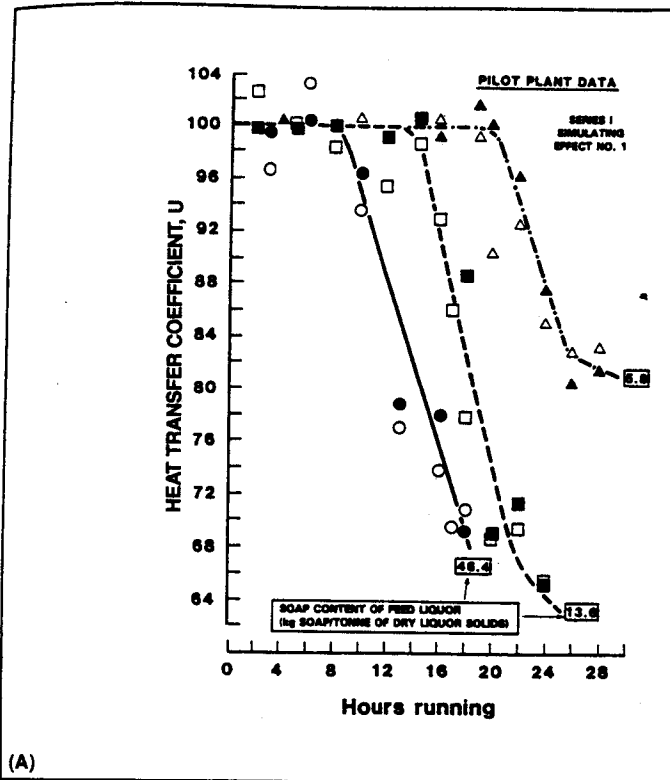


Fig. 4.3. Impact of soap content in liquor on evaporator heat transfer coefficient loss. (A) The vertical axis represents the overall heat transfer coefficient, U, as a % of the initial maximum; the horizontal axis is the hours running. (B) The vertical axis is the time, in hours, for a 15% reduction in the overall heat transfer coefficient for effect No. 1 or No. 1B; the horizontal axis is the soap content of liquor fed to the evaporator (17).

Fig. 4.4. Impact of soap deposition on rate of evaporator heat transfer coefficient loss. (A) The vertical axis is the soap loss across the evaporator effect; the horizontal axis is the soap content of the black liquor fed to the effect. (B) The vertical axis is the rate of decline in heat transfer coefficient, U, for effect No. 1; the horizontal axis is the soap loss across effect No. 1 (17).

however, the solids content of the liquor before evaporation tends to increase. As a result, the soap exhibits a greater tendency to separate in weak liquor storage tanks. The solubility of tall oil soap as a function of both temperature and solids content is illustrated in Fig. 4.5.

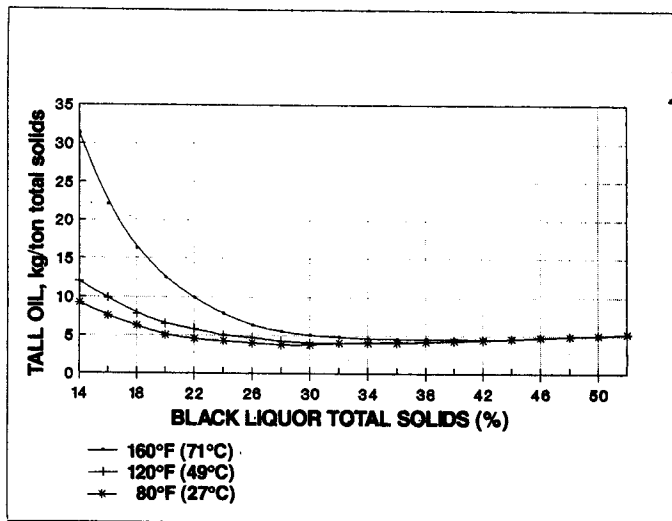


Fig. 4.5. Tall oil soap solubility as a function of temperature and solids content

Black liquor viscosity increases rapidly as the temperature decreases, so it is unlikely that lower evaporator skimmer temperatures would result in increased skimming efficiency (2).

Effect of the black liquor residual effective alkali content

Residual effective alkali (REA) content of the black liquor had a marked effect on the minimum solubility of soap in black liquor. This relationship is illustrated in Fig. 4.6.

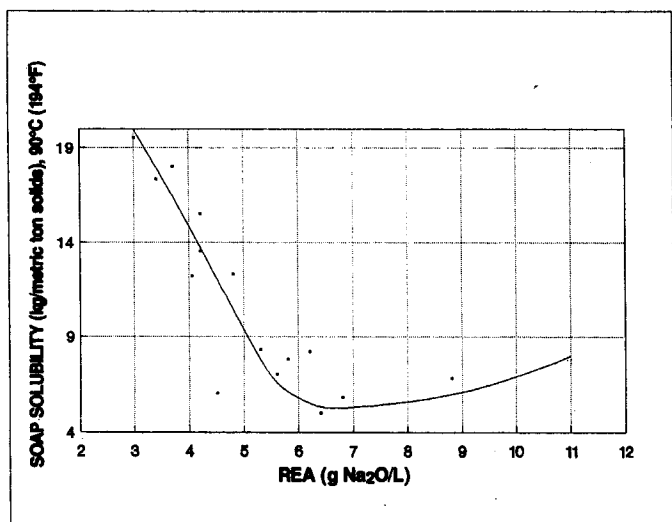


Fig. 4.6. Effect of residual active alkali on tall oil soap solubility (2)

Tall oil soap composition

Depending upon the species of the woods being pulped, ratios of fatty acid to resin acid vary. Soaps containing a higher ratio of fatty acids to resin acids showed lower solubility, as illustrated in Fig. 4.7.

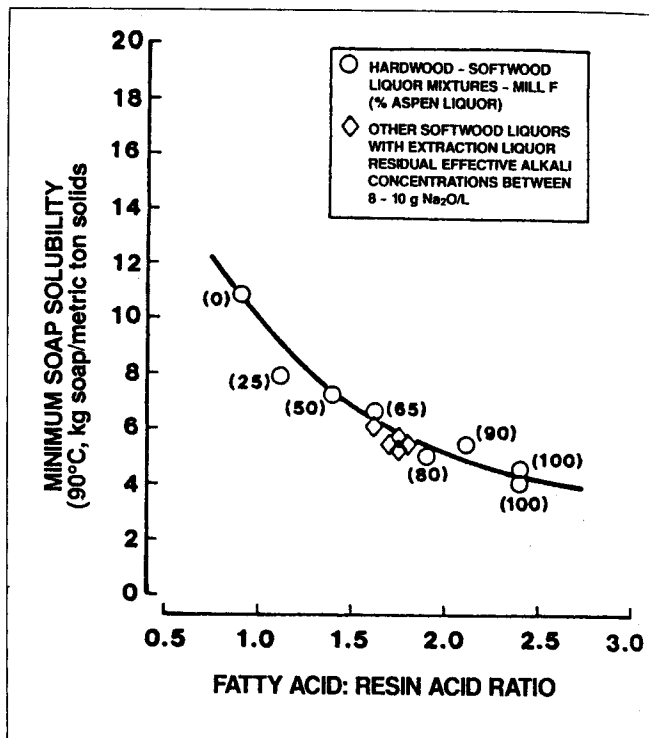


Fig. 4.7. Relationship of fatty acid:resin acid ratio in soap skimmed from black liquor to minimum soap solubility in black liquor (2)

Figure 4.8 is an illustration of the combined effect of lower effective alkali content and fatty acid:resin acid ratio.

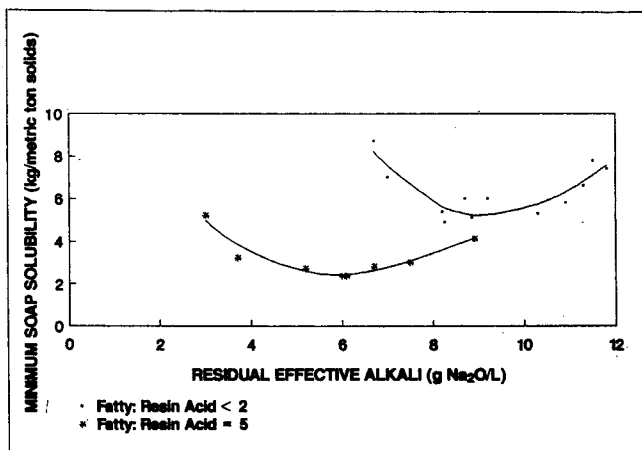


Fig. 4.8. Effect of fatty acid:resin acid ratio and effective alkali content on soap solubility (2)

Hardwood-Softwood Liquor Blending

Because observations of the influence of hardwood liquor blending have often been contradictory, a distinction should be made between hardwood liquor resulting from the kraft process and hardwood liquor resulting from the sodium sulfite semi-chemical (NSSC) process. Gooding and Wilkinson (13) showed that when hardwood liquor was blended with pine liquor from 0-25% on a solids basis, the residual tall oil soap content of the skimmed liquor decreased slightly. This finding was later confirmed up to 50% hardwood liquor solids content (2), but above about 60% hardwood solids content the tall oil soap solubility appeared to increase rapidly (Fig. 4.9).

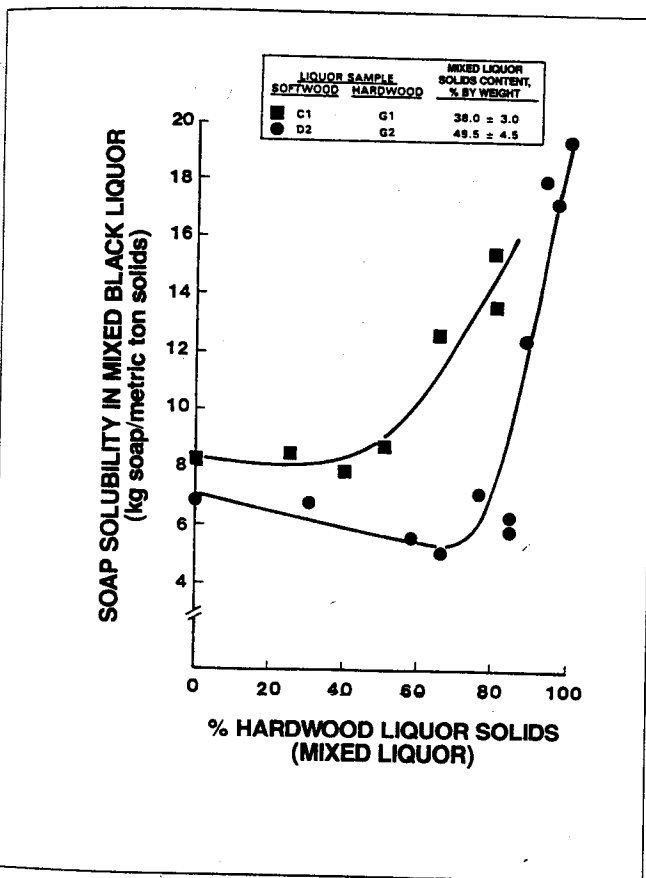


Fig. 4.9. Effect of hardwood liquor on soap solubility at 194°F (90°C) (2)

At high hardwood concentrations, the residual effective alkali level was low enough for the soap to solubilize; this would also account for much of the increase in solubility of the NSSC-pine kraft liquor mixtures (13).

Overall Tall Oil Balance

The type of process equipment determines the choice of tall oil soap recovery equipment. The change from conventional batch digesters and vacuum drum washers to cold blow digesters and diffusion, pressure drum, or belt washers has dramatically altered where soap separates from the liquor. Higher black liquor solids levels before

evaporation have resulted in greater soap separation in the weak liquor storage system. Soap balances around a batch digester/vacuum drum washer (14), and a Kamyrr/Two Stage atmospheric diffusion washer system (15), and a Kamyrr/vacuum drum washer are compared in Table 4.5.

Table 4.5. Tall oil material balance

| Pulp Type: | Linerboard | Bleached | Linerboard |
|---------------------|------------------|------------------|------------------|
| Digester: | Batch | Kamyrr | Kamyrr |
| Washer: | Vac. Drum | Diffusion | Vac. Drum |
| Year: | 1972 | 1985 | 1987 |
| | lb/o.d. ton wood | lb/o.d. ton wood | lb/o.d. ton wood |
| Tree | 112 | 91 | |
| Chips to Digester | 75 | 74 | 63 |
| Unwashed Pulp | 74 | 70 | 57 |
| Filtrate Recirc. | | 63 | 46 |
| Washer | 12 | 7 | 8 |
| Decker | 8 | | |
| To Weak Liq. Tank | 62 | 67 | 52 |
| Fr. Weak Liq. Tank | 60 | 21 | 31 |
| Fr. Evap. Skimmer | 12 | 9 | 7 |
| To Rec. Boiler | 11 | 9 | 7 |
| Sewer | 4 | 1 | 2 |
| Weak Liquor Soap | 2 | 46 | 21 |
| Evaporator Soap | 48 | 11 | 24 |
| Heavy Liquor Soap | 2 | 0 | 0 |
| Total Soap | 51 | 58 | 45 |
| | 100% | 100% | 100% |
| Recovery Efficiency | 68% | 78% | 71% |

The first stage wash liquor in 1972 had a dissolved solids content of about 13%, whereas the Kamyrr liquor in the 1985 study was about 19% dissolved solids. The 1987 study produced liquor at 15-17% dissolved solids. The increased solids dramatically increased weak liquor soap separation. This resulted in a dramatic increase in weak liquor soap recovery.

In some recent batch cold blow systems, the recirculation of soap saturated liquor is a significant operating difficulty because the soap evolves much earlier in the washing process and produces large volumes of foam. Changes in the management of the liquor during the heat recovery stages dramatically reduce the soap recirculation. The changes are dictated by soap solubility.

Soap Removal During Washing

Little data exist on the removal of soap in the washing process. The 1972 study by Cox and coworkers (13) of a three-stage vacuum drum washer was designed to determine the response relative to shower water flow and temperature. No correlations could be found between tall oil soap recovery and wash water flow rate or wash water temperature.

The tall oil soap in the washed pulp from any stage was directly proportional to the amount present in the feed to that stage. The washer was more efficient at removing dissolved solids than removing tall oil soap. In the later washing stages, dissolved solids were removed, but the

soap probably was reabsorbed into the fiber. It is, therefore, important to remove the soap foam before it has a chance to contaminate the next washing stage.

In studies of belt washers, the absence of washer vats and intermediate filtrate tanks was shown to inhibit the removal of undissolved soap. The washer does an excellent job of removing the dissolved soap and black liquor solids (see Table 4.6). However, at the discharge end of the washer, where the dissolved solids content is the lowest (less than 0.5% dissolved solids), the undissolved soap fraction is the highest (81%). Although the soap should be soluble, the absence of washer vats and filtrate tanks apparently does not allow time for the soap to dissolve or separate from the liquor before being reused. The undissolved soap is then filtered out on the pulp mat. Similar data for vacuum drum washers are not available.

Table 4.6. Soap distribution on a Chemi-Washer

| Filtrate | Black Liquor Solids (%) | Total CTO* on BLS (%) | Soluble Soap lb/min | Insoluble Soap lb/min | Fraction (%) | Total Soap lb/min |
|----------|-------------------------|-----------------------|---------------------|-----------------------|--------------|-------------------|
| Hdbx | 14.27 | 4.61 | 152 | 13 | 8 | 166 |
| 1st | 12.30 | 4.48 | 56 | 8 | 12 | 64 |
| 3rd | 7.41 | 4.33 | 16 | 6 | 27 | 23 |
| 4th | 3.68 | 6.07 | 11 | 7 | 38 | 17 |
| 5th | 1.62 | 21.10 | 5 | 20 | 79 | 25 |
| 6th | 0.51 | 35.30 | 3 | 11 | 81 | 13 |

*CTO = Crude Tall Oil

Soap Removal From Weak Liquor Tanks

It is becoming increasingly important to remove soap from weak liquor before evaporation. Typically, 40–80% of the soap recovered evolves in the weak liquor system. The primary means of removal is by foam breakers, which increase soap density from less than 0.5 lb/gal to about 3 lb/gal (see Fig. 4.10). The broken foam and its associated liquor is best sent to a common collection point for further densification; recombining the broken foam with the main liquor stream leads to soap fouling of operating equipment and re-entrainment in the liquor fed to the evaporators.

In the weak liquor storage tanks, the soap that separates may be removed by withdrawal ports on the side of the storage tanks. These removal ports should be at least 12 in. in diameter. Although the soap/liquor interface is usually determined manually, thermal conductivity and viscosity sensors have been used to detect this interface successfully (16).

The floating soap skimmer (15) is another device that has been used with some success for weak liquor skimming. The floating skimmer permits continuous soap recovery at any tank level, which can vary considerably. The skimmer is a conical steel vessel filled with a lead-water ballast. The water ballast level is adjustable when the

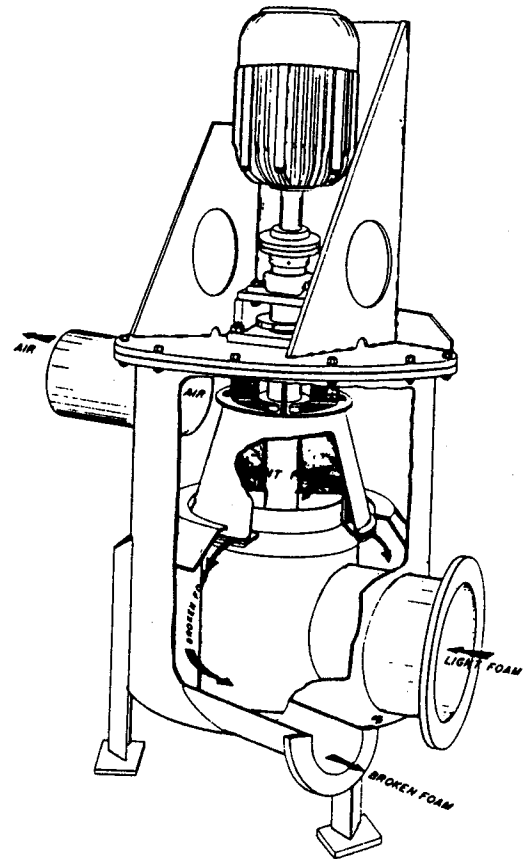


Fig. 4.10. Foam concentrator
(Courtesy A.H. Lundberg Associates)

skimmer is in operation. The buoyancy of this device is adjusted so that it floats near the surface of the liquor. The conical skimmer is connected to 10-in. stainless steel piping by ball joints. The skimmer level and the amount of soap are normally measured by gauge board level indicators mounted on the side of the tank. Normal practice has been to maintain a 6–10-ft. head of soap or foam above the skimmer to maximize soap density and minimize liquor entrainment. One mill uses pump pressure to detect when the soap liquor interface has been reached. Due to the high viscosity of soap, the pump discharge pressure decreases sharply when liquor is being pumped. The pressure sensor then automatically shuts off the pump. This system is illustrated in Fig. 4.11.

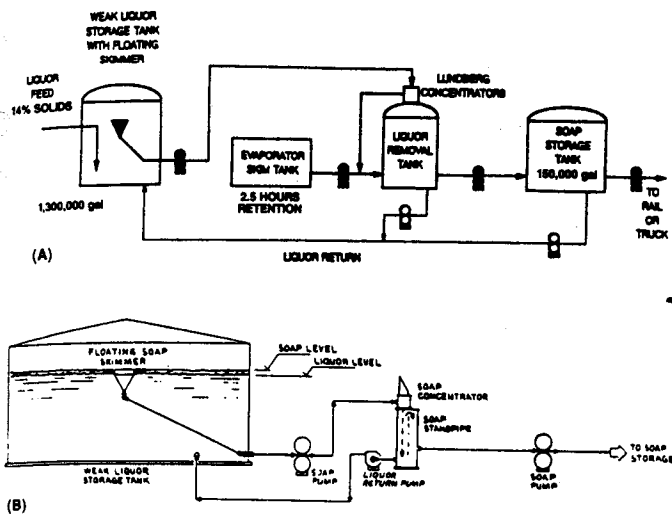


Fig. 4.11. The effective use of a floating soap skimmer (Courtesy of Proctor & Gamble-Flint River, and A. H. Lundberg)

Soap Removal From Evaporator Soap Skimmers

Skimmer Design

Skimmer Efficiency Determination

The efficient operation of a soap skimmer is best determined by comparing the difference between the feed and discharge tall oil residual (PCA 24) with the difference between the feed and the solubility limit. Placing the skimmer at the location where the dissolved solids content is about 25% is usually optimal. In a study (17) done on a variety of Canadian soap skimmers, soap removal efficiency varied widely. Simply having a large skimmer residence time was not sufficient to ensure high soap skimming efficiency.

Soap Particle Rise Rates and Liquor Downdraft

Soap rises slowly, 3.5–25 ft/h (1.2–7.6 m/h) (18), and will not separate if it does not have sufficient time to reach the liquor surface. Also, the soap particles must rise against an overall liquor downdraft or superficial velocity, which is defined as the skimmer depth divided by the residence time. The removal efficiency plotted against the skimmer superficial velocity is essentially linear; at a superficial velocity of 3.3 ft/h (1 m/h), the recovery efficiency was greater than 90%, as expected from earlier studies. The effect of superficial liquor velocity on soap skimming efficiency is illustrated in Fig. 4.12.

Skimmer Baffling

The superficial liquor velocity accounted for 90% of the variability in the data shown in Fig. 4.12. The remainder can be accounted for by other factors including: liquor short-circuiting, soap/liquor interface location, and the relative location of the skimmer feed and outlet.

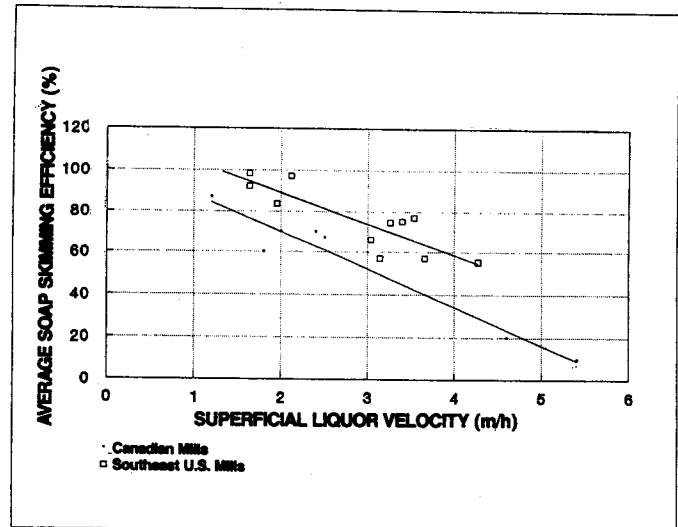


Fig. 4.12. Effect of superficial liquor velocity on soap skimming efficiency in Canadian and southeastern United States

Adjustments to skimmer baffling have improved skimming efficiency (19); in general, the baffling should be kept simple. The more changes in liquor direction, the more turbulence is generated, which subsequently decreases soap removal. Recommended baffling alternatives (1) include rectangular soap skimmers, which provide high efficiency, and circular soap skimmers, which use highest efficiency spiral baffles (20). The liquor linear velocity (feed rate divided by channel area) should be less than 2.4 ft/h (0.73 m/h). At lower velocities, solids will settle in the skimmer.

Liquor Level Control

Another source of skimmer upset is varying liquor level (20). The overflow standpipe and adjustable weir provide stable level control and a means to control the liquor interface.

Soap Bed Depth

The soap bed depth should be minimized directly above the skimmer liquor exit (20,21). Soap beds that are too thick result in re-entrainment of the soap particles in the liquor leaving the skimmer. Soap beds that are too thin result in excessive liquor carryover, and may also contribute to soap re-entrainment due to thermal convection currents and soap scraper convection currents. Soap bed depths should never exceed 2 ft (0.7 m) immediately before the soap collection trough. One of the best indicators of soap bed depth is temperature. Generally, the soap bed is 20–30°F (10–15°C) cooler than the liquor temperature. Soap taps on the side of an enclosed skimmer can also be used to determine the soap bed depth.

Methods for Increasing Soap Skimmer Efficiency

Skimmer feed solids, baffling, liquor entry point, level control, and bed depth are basic to skimmer efficiency and thus should be optimized first. These basics should achieve

outlet residuals below 6 lb CTO/1000 lb black liquor solids (0.6 kg/100 kg) on a skimmer with more than 3 h retention time. Smaller skimmers, tall skimmers, or skimmers whose baffling cannot be easily altered require additional methods. These are air injection, electroflocculation, and chemical additives.

Air Injection

The simplest and least expensive method of improving skimmer efficiency is through air injection. Small quantities of air injected into the skimmer feed improved skimmer efficiency up to 22% (20,15,17). In achieving this, it is critical that the air be finely atomized. An equally important finding was that a little bit of air was good, but much more air was bad. All three studies indicated the optimum amount was 1 scfm (standard cubic feet per minute)/1000 gpm (gallons per minute) (7.5 L/m³). The use of higher air flows reduced skimmed liquor soap residuals slightly, lowered the skimmed soap density, and increased the black liquor entrained in the skimmed soap. When correctly adjusted, air injection should result in a soap density of about 6.6 lb/gal (0.75 kg/L) as illustrated in Figure 4.13.

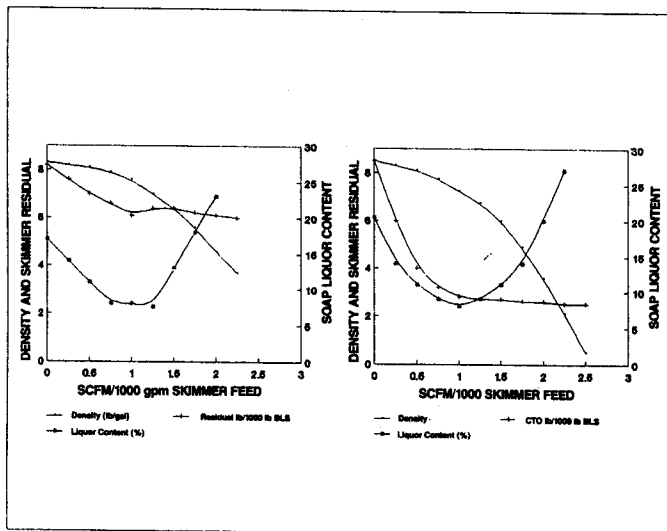


Fig. 4.13. Effect of air injection on skimmer efficiency at (A) 90 minutes residence time (20) and (B) 150 minutes residence time (15)

To achieve good atomization, most mills inject the air into the suction side of the skimmer feed pump. At air flows of 1 scfm/1000 gpm (7–7.5 L/m³), pump cavitation is not a problem. One mill has used a sintered metal tube to provide finely atomized air on the pressure side of a skimmer feed pump.

Several mills have applied air injection to large, well designed soap and have seen little benefit in skimming efficiency. Control of the soap bed depth has been more consistent. This should reduce the potential for soap particle re-entrainment.

Electroflocculation

The fine particles of tall oil soap that are suspended in black liquor and normally lost in the liquor going to the recovery furnaces can be electrically charged. Subsequently, these particles agglomerate and form larger particles which separate readily. A corona wind discharge directed against the surface of the black liquor causes the small particles to collect and float to the top of the skim tank. The potential used varies from 10,000 V to 100,000 V. The direct current flow is low, usually fractions of a milliamper (1).

A similar effect can be attained by immersing direct current electrodes into a stream of black liquor. The voltage used is below the decomposition potential of water. A commercial process (22–23) has been reported that can reduce skimmer outlet residuals by application of an electric field to a liquor stream (as illustrated in Table 4.7. The electroflocculator, which included mechanical air atomizer, was effective in increasing pilot skimmer efficiencies).

Table 4.7. Electroflocculator results of pilot trials in five mills

| | Mills | | | | |
|-----------------------------|-------|------|------|------|------|
| | A | B | C | D | E |
| Tall Oil Leaving Skimmer | | | | | |
| No electroflocculator | 12.4 | 22.0 | 10.0 | 6.3 | 13.0 |
| With electroflocculator | 5.5 | 15.5 | 4.3 | 5.2 | 5.5 |
| Fatty Acid/Rosin Acid ratio | 0.91 | 0.56 | 1.43 | 0.87 | 0.83 |
| Solubility limit | 5.0 | 7.0 | 3.5 | 5.0 | 5.0 |
| Efficiency | | | | | |
| No electroflocculator | 80% | 56% | 67% | 87% | 63% |
| With electroflocculator | 99% | 75% | 96% | 98% | 98% |
| Improvement | 24% | 34% | 43% | 12% | 56% |

A mechanical air atomizer was used in the feed stream ahead of the electroflocculator to aid in soap separation; about 10–20% efficiency improvement is due to air flotation (17,20).

In one mill that used a digester additive to enhance liquor penetration, the additive also prevented soap flocculation during washing by increasing the soap solubility. Although this helped soap removal during washing, the soap did not separate effectively in the soap skimmer and seriously fouled the evaporators. The electroflocculator effectively helped the agglomeration of soap particles and significantly improved recovery.

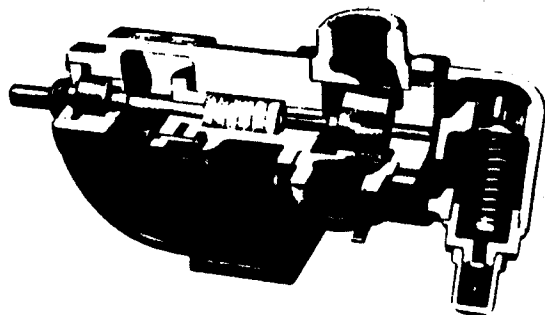
Chemical Additives

The effectiveness of proprietary additives to help soap recovery has been evaluated (17,22). One commercial surfactant added at the suction of the skimmer feed pump significantly increased soap skimming efficiency in all mills at dosages as low as 0.6 ppm. Two similar cationic polyamides supplied by a second company had no effect on soap skimming efficiency.

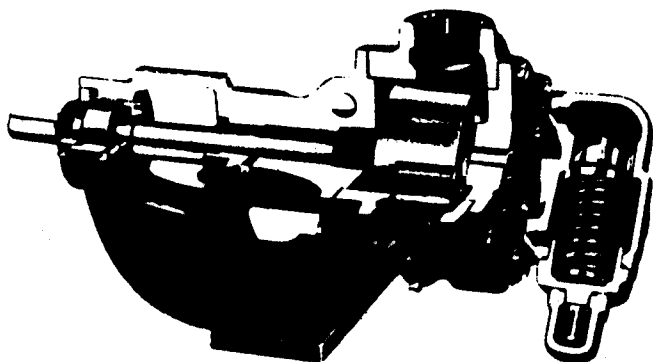
Soap Handling Equipment

Pumping

Due to its high viscosity, soap is best pumped with a positive displacement pump, typically a gear pump. If the pump contains an internal pressure relief valve, the valve should be set to above 75 psi. Failure to set the internal pressure relief high enough will result in frequent soap trough and soap tank overflows. The pumps should be checked regularly for wear. Spare pumps should be valved using positive closure ball valves, and should be isolated when not in service. Steam clean-out lines should be available and used whenever a soap pump is placed on standby (see *Figure 4.14*). Check valves should never be used in soap lines because they are readily fouled by the soap.



Cutaway View—(Packed type)



Cutaway View—(Mechanical Seal Type)

Fig. 4.14. Cutaway views of typical soap pumps including the pressure relief recycle fitting.
(Courtesy Houdaille Industries, Inc., Viking Pump Division)

Soap Densification

The first stage of soap densification occurs in the weak liquor storage area. Traditionally this is done using a foam tower, which is a tall, narrow tank with a foam breaker at the top. Mechanical soap densification equipment is designed to operate in two ranges. The first range is very low density soap such as washer foam. A foam concentrator is a single stage centrifuge that collapses the foam, which then flows along the wall of the centrifuge bowl. Air separated from the foam is discharged to the atmosphere. The collapsed foam density is normally 0.5–1 lb/gal (0.06–0.11 kg/L) (25,26). Light soap overflows the weak liquor storage/filtrate tank into the foam tank. The mass of the liquor laden soap partially collapses and densifies the soap, which is then transferred to a decanter for liquor removal. The resulting foam density is usually less than 2.5 lb/gal (0.3 kg/L). The liquor content of this dense foam is usually more than 50%. This material is difficult to pump.

The foam tank system is being replaced by the use of a soap collection tank and soap concentrator arrangement (27), which is depicted in *Fig. 4.15*. Soap recovered from the weak liquor storage is gravity fed into a soap tank. Liquor settles to the bottom and is returned to weak liquor storage. The soap overflows at a point about 3 ft (1 m) above the liquor return line, then passes through a soap concentrator. The soap concentrator is similar to the foam concentrator, but produces a soap with a density of 5–8 lb/gal (0.6–0.9 kg/L) that can be readily pumped in conventional soap pumps.

Soap/Liquor Separation in Storage

Traditionally, soap storage has been designed not so much as storage, but as a retention tank that allows time for the liquor to drain from the soap. The soap discharged from the skimmer normally has a liquor content of 10–25% by weight, although weak liquor soap can contain as much as 50% black liquor by weight. Black liquor in the soap increases the cost for shipping liquor to a tall oil plant, as it is common for mills to be penalized for excess liquor in the soap. The excess liquor in the soap also increases the cost of converting soap to crude tall oil with sulfuric acid.

The preferred method for effectively decanting the liquor from the soap is to feed the soap into a tank with a conical bottom. If such a tank is not available, the soap should be cascaded through two soap storage tanks. Liquor that separates from the bottom of the tanks should be returned to weak liquor storage. The distance between the liquor withdrawal port and the soap withdrawal port should be at least 3 ft (1 m). Soap should only be shipped or pumped for acidulation from the second tank in the cascade (27).

A new device for releasing liquor from soap was reviewed (16). This soap rake is depicted in *Fig. 4.16*. The device consists of a rotating arm with fingers that gently move through the soap and provide both a collection point and a drainage path for the liquor. The rake is installed so that the

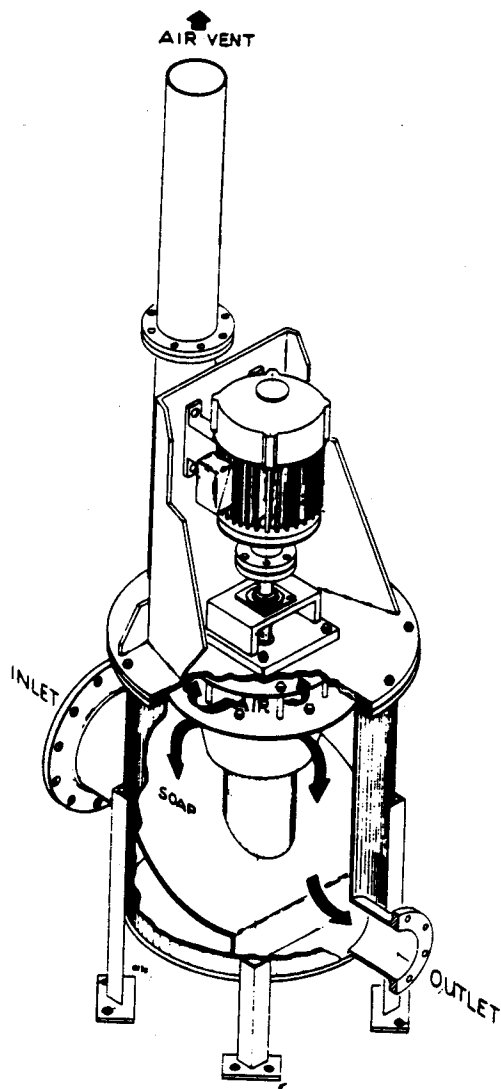


Fig. 4.15. Soap concentrator
(Courtesy A.H. Lundberg Associates, Inc.)

lower end of the fingers are in the liquor layer at the bottom of the storage tank. The soap rake was able to reduce the liquor content of the incoming soap by 50% or more. The main criteria for ensuring good performance is to maintain a uniform feed rate within the design limits and to accurately sense and control the soap/liquor interface.

Soap/Liquor Interface Detection

Soap fouling is the main problem with interface detection in closed vessels such as soap decanters. Two sensors have been successful. Since soap has a much lower thermal conductivity than black liquor, a thermal conductivity probe has been used to control the soap liquor interface (16). This probe uses a three element head, one of which is a heated probe that melts the soap and avoids fouling. Similarly, soap has a much higher viscosity than liquor, a viscosity probe has been used. Both have been used to start and stop liquor pumps.

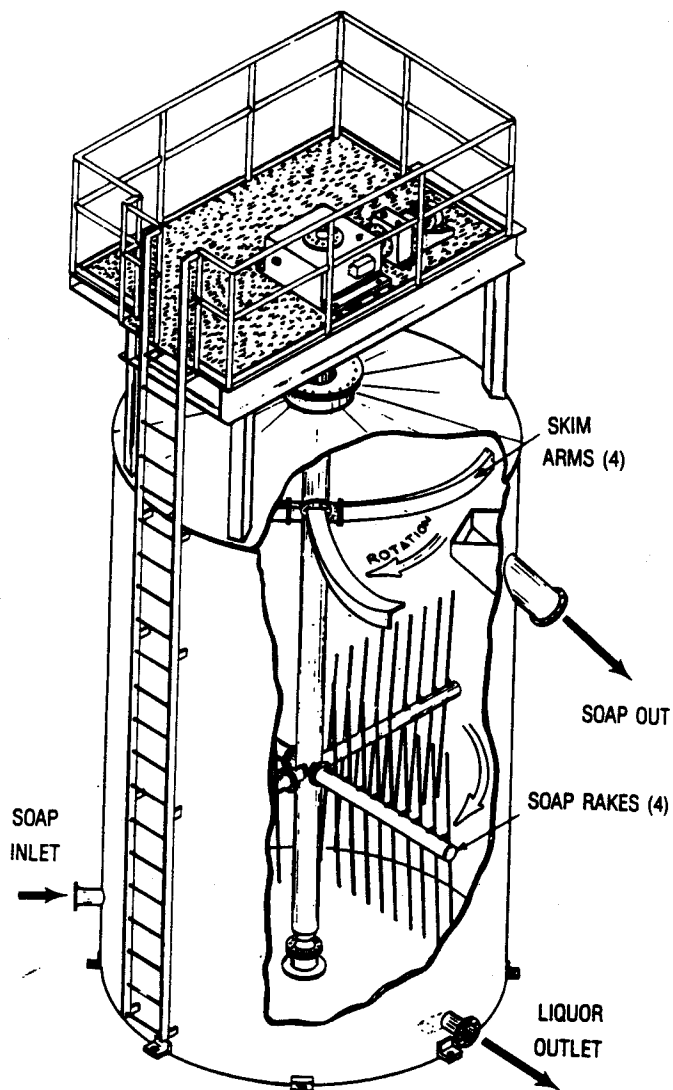


Fig. 4.16. Soap rake for releasing liquor from soap
(Courtesy A.H. Lundberg Associates, Inc.)

Other Factors In Tall Oil Soap Recovery

Useful Analytical Methods

Soap Density

Most of the processing equipment is sensitive to soap density, so this is one of the simplest and most useful measurements. Soap density can readily be determined using a 1-liter beaker, which should be filled and levelled using a spatula. The measured density should be adjusted for the liquor content; the adjusted density should be used for diagnostic purposes.

Soap Liquor Content

One of the simplest methods of determining the liquor content of soap is to centrifuge a 15 mL sample at 1500

rpm for 30 sec. The sample should be kept as close as possible to the temperature at which it was sampled to ensure meaningful results. The liquor content can be determined by observing the location of the soap/liquor interface. The measured soap density should be adjusted for the liquor content to calculate the liquor free soap density.

Black Liquor Tall Oil Residual Content

The residual tall oil (soap) content is considered the most useful test when determining skimmer performance. The only widely accepted method is the modified Buckeye procedure, PCA 24 (28). Sample collection is the most important step. When liquor cools, at a given solids concentration, soap comes out of solution; once out of solution, soap is difficult to return to solution because a small portion usually remains on the wall of the sample container. To prevent the soap from coming out of solution during storage before analysis, the liquor should be sampled into water. Enough water should be present to ensure that the diluted solids do not exceed 4% dissolved solids. Table 4.8 shows the quantity of water that should be used for collecting 500 mL and 1-L samples at different feed liquor concentrations.

Table 4.8. Black liquor sampling dilution data

| Black Liquor Solids Contents (%) | Proportions Necessary to Obtain 4% Solids | | | |
|----------------------------------|---|---------------|--------------------------------------|---------------|
| | 1 Pint (473 mL) Total Volume | | 1 qt (946 mL) Total Volume | |
| | (BL × Water) Black Liquor (mL) | Water (mL) | (BL × Water) Black Liquor (mL) | Water (mL) |
| 55.0 | 34 | 439 | 69 | 877 |
| 50.0 | 38 | 435 | 76 | 870 |
| 45.0 | 42 | 431 | 84 | 862 |
| 40.0 | 47 | 426 | 95 | 851 |
| 35.0 | 54 | 419 | 108 | 838 |
| 30.0 | 63 | 410 | 126 | 820 |
| 27.5 | 69 | 404 | 138 | 808 |
| 25.0 | 76 | 397 | 151 | 795 |
| 22.5 | 84 | 389 | 168 | 778 |
| 20.0 | 95 | 378 | 189 | 757 |
| 17.5 | 108 | 365 | 216 | 730 |
| 15.0 | 126 | 347 | 252 | 694 |
| 12.5 | 151 | 322 | 303 | 643 |
| 10.0 | 189 | 284 | 378 | 568 |
| 7.5 | 252 | 221 | 505 | 441 |
| 5.0 | 378 | 95 | 757 | 189 |

Calculations:

Let B = mL black liquor necessary (unknown)

T = Total volume of black liquor water desired (mL)

S = Black liquor solids content (%)

$$0.04 = S \cdot B \cdot 0.01 / T$$

Spent Acid Assimilation

In mills where the black liquor soap is converted to tall oil, an additional complication is how to recycle the spent acid from the tall oil plant. Although this spent acid is

usually called neutralized spent acid, it is neither acidic nor neutral and hence would more accurately be called tall oil plant (TOP) alkaline brine. Mills successfully return the TOP brine at three separate locations: (1) to the batch digesters as fillback liquor; (2) in the feed to the black liquor evaporator or evaporators; and (3) in the feed to the recovery boiler concentrators.

In all three locations, strict control of the TOP brine pH is recommended. Return of the TOP brine at a pH below 7 will result in the evolution of toxic hydrogen sulfide (H₂S) gas. In most mills the pH is controlled to above pH 10. At this pH the unrecovered resin acids and fatty acids are fully saponified. Depending upon the point of return, the TOP brine may need to be controlled to a higher pH. The brine will contain some residual salts (CaSO₄ and others) and dirt, and the storage tank must be well agitated. A recycle stream off the pump-out line is recommended to control pH and to help keep the tank clean.

Batch Digester Fillback

Return of the TOP brine to the batch digesters should be done at a pH above 10, and the brine should be returned to the fillback liquor holding tank. When the level in the tank is low, the first-stage washer filtrate should be used to control the level. Return to the digesters results in an increased evaporator load; the water is evaporated at about 6 steam economy.

Evaporator Feed

The water in the TOP brine is evaporated at an economy of about 6, with the pH controlled above 10. The feed rate should not exceed about 1.5% of the total liquor fed to the evaporator; at this rate it will decrease the soluble scale precipitation point 1–2% (29, 10). If the feed rate is likely to exceed 1.5% of the total, the fraction of the solids that will settle in the TOP brine should not be returned. This fraction contains about 80% of the unrecovered soap content of the TOP brine. The soap contained in the TOP brine adds to the load on the soap skimmers, and contains fiber and calcium salts that could accelerate evaporator fouling. If the solids are removed, then the soluble scalants such as soap are removed also.

The settleable solids in the dilute spent acid (13–17%) have been shown to be less dense than the black liquor solids at 22–25%, and therefore do not separate efficiently in the skimmer. This material should be removed, as it is of sufficient volume to plug the evaporator tubes.

Additional NaOH to increase the pH above 12 to fully solubilize the lignin is of marginal value. This would lower the critical solids concentration for Na₂CO₃–Na₂SO₄ saturation, and would likely increase soluble scale formation.

Return to the Heavy Liquor System

TOP brine that is returned to the heavy liquor system must be carefully metered in at a point where it can be well mixed in order to decrease the overall solids level. Evaporation of the water will be at an economy of less than one. If this brine is fed to a liquor crystallizer/concentrator, it will

have minimal effect on soluble scale formation because these devices are designed for supersaturated Na_2SO_4 solutions.

The brine must be treated with 50% NaOH to neutralize any residual acids and to fully redissolve the lignin. About 9 gal NaOH/ton of CTO is required. White liquor cannot be used for this purpose because it can only increase the pH to about 11, which is not high enough to minimize lignin precipitation.

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Chapter 8

Lime Reburning: The Rotary Lime Kiln

by Venki Venkatesh

Introduction

Lime reburning is the process of converting lime mud sludge (essentially, calcium carbonate, CaCO_3) generated in the causticizing plant to reburned lime (calcium oxide, CaO). This reaction called calcination takes place at high temperatures (1500°F and higher) in a rotary lime kiln, which is both a chemical reactor and heat transfer device.

The North American paper industry began using kilns in the mid-1920s. Early kilns had two supports and were relatively small, 6–8 ft (1.8–2.4 m) in diameter and 100–140 ft (30–40 m) long. They were also energy inefficient; fuel consumption rates as high as 20 million Btu per ton of product were not uncommon.

The cement industry pioneered the use of longer, more energy efficient kilns. Modern versions have three or more supports and typically are over 10 ft (3 m) in diameter and over 280 ft (85 m) long. Rising fossil fuel costs have led to fuel efficiencies of 6 million Btu per ton of product. *Table 8.1* summarizes two-support and three-support installations in North America.

Table 8.1. Lime mud kilns installed in North America

| No. Supports | Pre-1945 | 1945–64 | 1964–78 | 1978–89 |
|----------------|----------|---------|---------|---------|
| Two supports | 98 | 47 | 16 | 0 |
| Three supports | 2 | 93 | 94 | 88 |

Overview of lime reburning process

The conversion of lime mud sludge to lime is an important step in the production of white cooking liquor in the kraft chemical recovery process. In essence, the process turns lime mud (CaCO_3) into reburned lime (CaO) and carbon dioxide (CO_2). Lime mud sludge is washed to remove the residual cooking liquor and then dewatered on a precoat type vacuum filter to a solids content of 68% or more. The dewatered mud cake is fed to the lime kiln where calcination occurs. The kiln product—reburned lime—is sent to a green liquor slaker. *Figure 8.1* illustrates the lime process loop. The causticizing and lime reburning processes are extremely interdependent.

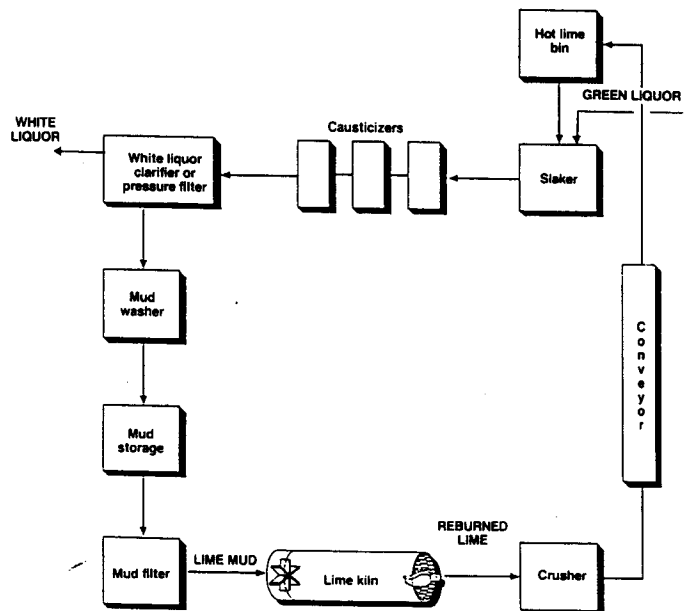


Fig. 8.1. Lime reburning process flow loop
(Courtesy Termorak, Inc.)

Lime product quality

Quality variations in the reburned lime product can cause problems during green liquor slaking and causticizing. Ideally, reburned lime should be soft, 3/4-in. (2 cm)-diam. pebbles. Reburned lime quality is judged in terms of availability, residual calcium carbonate, and reactivity.

Availability

This quantity refers to the fraction of lime (as CaO) present in the reburned lime product that is available for slaking. Pure lime will have an availability of 100%. Impurities such as iron oxide, silica, and alumina in the lime, as well as unreacted calcium carbonate, will reduce the availability. The typical range in pulp mill kilns is 87–92% availability of reburned lime. Availability can be used to identify the buildup of inert materials in the lime loop.

Residual calcium carbonate

The residual carbonate test is easy to perform and is useful for kiln control. Because some unburned calcium carbonate is always present in the reburned lime, to avoid overburning the calcination reaction is never completed. Operators typically will set a target of 1.5–2.5% for residual calcium carbonate content in the reburned lime. Generally, this is done by adjusting the calcination temperature. *Figure 8.2* shows the relationship between temperature and unburned carbonate. Levels below about 1.5% involve very high calcination temperatures and will result in overburning.

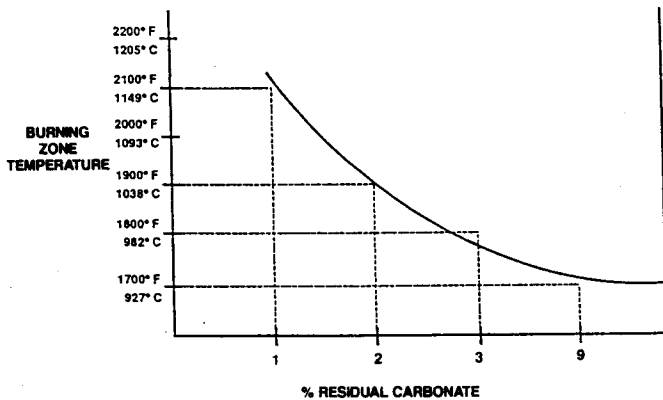


Fig. 8.2. Calcination temperature vs. residual carbonate in reburned lime. (Courtesy Termorak, Inc.)

Reactivity

The calcium oxide in the reburned lime must slake quickly and completely in the green liquor slaker to ensure white cooking liquor causticity targets. A highly reactive lime will have a porous structure and will slake within 5 min. A poorly reacting lime will have been overburnt by calcining at high temperatures, usually above 2100°F (1149°C). Impurities such as sodium or silica tend to block the pores and impair reactivity. Poorly reacting reburned lime can take 15–20 min or more to slake, causing bottlenecks in key recausticizing plant equipment.

Process stages in lime reburning

The lime kiln is divided into four functional zones (see *Fig. 8.3*), which represent the stages in the conversion of lime mud to reburned lime. *Figure 8.4* illustrates a typical temperature profile of the converting material as it progresses through the kiln.

In the drying stage, water is evaporated from the wet mud, which typically enters the kiln with a solids content of 68% or more. Drying is accomplished as the mud passes a series of metal chains attached to the kiln shell, which are heated by the incoming hot flue gases. The chains are designed to dry the mud to about 95% solids, although some designs dry the mud to zero moisture content. The chains also act as dust curtains to minimize the amount of lime dust lost with the flue gases exiting the kiln.

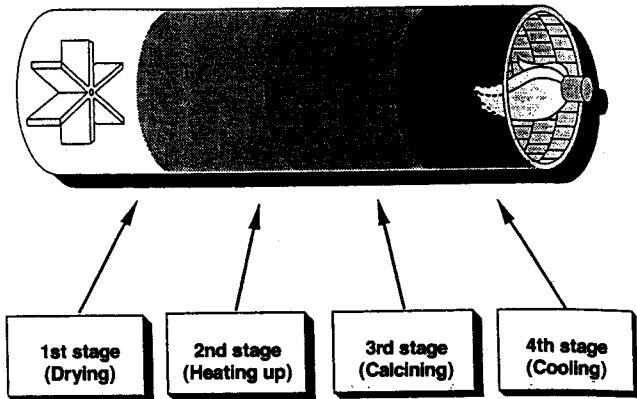


Fig. 8.3. Lime reburning process stages (Courtesy Termorak, Inc.)

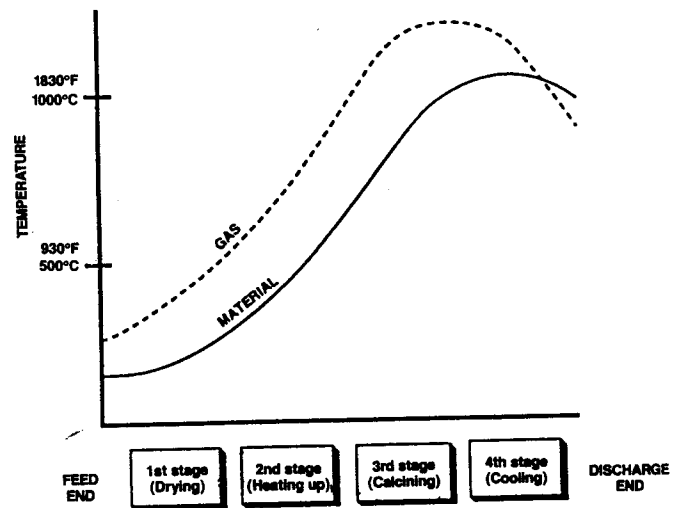


Fig. 8.4. Kiln temperature profile (Courtesy Termorak, Inc.)

In the second stage, the dried mud is heated by heat transfer devices such as tumblers and lifters that are attached to the kiln shell. These lifters and tumblers stir the lime and promote good mixing of the material with the hot flue gases. In some kilns, mixing shields and steel bars are included in the heating-up zone to further improve heat transfer.

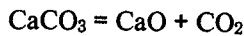
Calcination takes place in the third zone, where carbon dioxide gas is released and calcium oxide pellets begin to form. The ideal lime pellet is about 3/4 in. (2 cm) in diameter; if the mud is not properly dried and heated, large lime balls can form in the kiln. This reaction is temperature dependent; a minimum temperature of 1500°F (815°C) is required for calcination to occur. Temperatures over 2100°F (1149°C) result in overburnt lime with poor slaking properties, and also damage the kiln's refractory lining.

Cooling, the final stage, occurs as the pellets pass under the burner and move to the discharge end of the kiln. The hot lime pellets will cool down and exchange heat with the incoming secondary air flow.

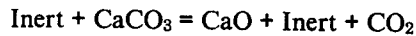
Heat balance

A knowledge of heat balance is important in the design of new kilns and in the analysis of existing ones.

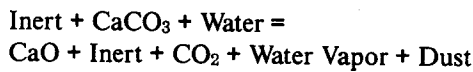
The basic reaction in a rotary kiln is:



If impurities in the feed and residual CaCO_3 are considered inert, a new equation more nearly describes the process in a rotary kiln as follows:



Furthermore, dust is discharged in the flue gas from the kiln, and the lime mud fed to the kiln contains water. Thus, the final equation for a material balance is as follows:



A mass and energy balance for two kilns specified in Table 8.2 are shown in Table 8.3.

Table 8.2. Sample specifications for two kilns^{1,2}

| Kiln geometry | | |
|--|------------------------|------------------------|
| | Single-brick insulated | Double-brick insulated |
| Diameter (ft) | 13 | 13 |
| Length (ft) | 350 | 350 |
| Slope (in./ft) | 0.31 | 0.31 |
| Operating conditions | | |
| Feed temperature (°F) | 110 | 110 |
| Production rate (tons/day) | 360 | 360 |
| Dust loss (%) | 10 | 10 |
| Mud solids (%) | 70 | 70 |
| Availability (%) | 95 | 95 |
| Speed (RPM) | 1.3 | 1.3 |
| Ambient temperature (°F) | 77 | 77 |
| Wind velocity (MPH) | 5 | 5 |
| Product temperature (°F) | 1950 | 325 |
| Backend temperature (°F) | 576 | 330 |
| Heat rate (million Btu/ton CaO) | 8.55 | 6.22 |
| Refractory system | | |
| Chain configuration | | |
| Total area (ft ²) | 5800 | 5800 |
| Density (ft ² chain/ft ³ kiln) | 2 | 2 |
| Start (ft from discharge) | 314 | 314 |
| Firing conditions | | |
| Fuel type | Fuel oil | Fuel oil |
| Gross heating value (Btu/lb) | 18,145 | 18,145 |
| Flame length (ft) | 65 | 65 |
| Excess air (%) | 20 | 20 |
| Product coolers | | |
| | No | Yes |

Table 8.3. Sample mass and energy balances for two kilns^{1,2}

| | 13×350-ft kiln | 13×350-ft kiln |
|---|-------------------------|-------------------------|
| | No product coolers | Product coolers |
| | Single-brick refractory | Double-brick refractory |
| | Fuel oil | Fuel oil |
| MASS BALANCE | | |
| Feed: | lb/ton CaO | lb/ton CaO |
| CaCO ₃ | 3571 | 3571 |
| Inert | 105 | 105 |
| Water | 1750 | 1750 |
| Dust | 408 | 408 |
| Fuel and combustion air: | | |
| Fuel | 482 | 353 |
| Air | 7671 | 5615 |
| Total input = | 13,987 | 11,802 |
| Lime product: | lb/ton CaO | lb/ton CaO |
| CaO | 2000 | 2000 |
| Inert | 105 | 105 |
| Exhaust gas: | | |
| Combustion products | 8153 | 5968 |
| CO ₂ from calcination | 1571 | 1571 |
| Water vapor | 1750 | 1750 |
| Dust | 408 | 408 |
| Total input = | 13,987 | 11,802 |
| ENERGY BALANCE | | |
| Evaporate and heat water | Million Btu/ton CaO | Million Btu/ton CaO |
| 1750 $\frac{(175-110) + 993 + 0.47(576-175)}{10^6}$ | 2.18 | 1.98 |
| Energy in kiln product | | |
| 2105 [0.24 (1950-110)] / 10 ⁶ | 0.93 | 0.11 |
| Enthalpy of calcination | | |
| 3571 [768] / 10 ⁶ | 2.74 | 2.74 |
| Enthalpy in CO ₂ from calcination | | |
| 1571 [0.235 (576-110)] / 10 ⁶ | 0.17 | 0.08 |
| Energy in dust | | |
| 408 [0.24 (576-110)] / 10 ⁶ | 0.05 | 0.02 |
| Enthalpy of combustion products | | |
| 8153 [0.26 (576-77)] / 10 ⁶ | 1.06 | 0.39 |
| Radiation loss | | |
| radiation + convection | 1.21 | 0.78 |
| Net Energy = | 8.34 | 6.10 |
| Fraction of fuel gross heating value available @ 77°F | 0.953 | 0.953 |
| Heat Rate = | 8.75 | 6.40 |

Effect of impurities in lime mud feed

The calcium carbonate content of mud fed to the kiln typically ranges from 94-95%. Table 8.4 shows the chemical composition of an acceptable lime mud. It is imperative that the feed mud cake be well washed in the precoat filter, although the impurities effect the formation of nodules to

some degree; if the lime mud feed to a kiln were 100% calcium carbonate, no nodules would form and the kiln would be extremely dusty.

Table 8.4. Chemical composition of lime mud feed

| Component | Composition (%) |
|-------------------|-----------------|
| Calcium carbonate | > 95 |
| Sodium oxide | < 0.2 |
| Silica | < 0.2 |
| Alumina | < 0.5 |
| Iron oxide | < 0.5 |
| Sodium sulfide | < 0.01 |
| Calcium oxide | < 0.5 |

Soda (Na_2O) is the major impurity in lime mud. The target for modern precoat filters is a mud soda content of 0.2% or less. A poorly washed mud will have a tendency to build rings or form large balls within the kiln. Rings or balls restrict production and kiln efficiency by causing the kiln to be shutdown for cleaning.

Lime mud containing minimum amounts of reduced sulfur compounds (Na_2S) is required to meet stringent kiln odor emission standards. Washing to a soluble soda content of 0.2% or less has recently been accepted as a means to ensure low sulfide content. Many lime kilns incinerate sulfur-bearing noncondensable gases (NCG), which has contributed to severe problems with rings. Fuel oils with high sulfur contents are another sulfur source.

Alumina, silica, and iron oxide enter the lime loop as impurities in the makeup lime, from dregs carryover, and from the kiln refractory. Their impact is to reduce lime availability.

Impurities are also associated with the common calcining problems of balling and ringing. Ball formation typically occurs just past the chain section or just ahead of the kiln burning zone, and is associated with high soda, free lime, and moisture content in the incoming mud. Soda and sulfur compounds have lower melting points and consequently tend to coat the lime pellets and large balls that form and roll down the kiln. The mud balls can be several feet in diameter, and they have a white surface with a green or yellow core; their composition is that of unburnt mud.

Balling problems can be reduced by minimizing mud feed flow or moisture content variations. A mud feed solids of 70% and low soda content can also greatly minimize the formation of balls.

In many modern mills, a more persistent problem is the accumulation of hard ring deposits on the refractory lining. Ring formation has been attributed to high levels of sulfur and/or sodium in the mud feed. In extreme cases, rings can severely constrict the flow of reburned lime and exhaust gases inside the kiln and reduce the lime throughput.

Three type of rings have been identified in lime kilns: (1) mud rings, which occur in the chain section, are due to wet mud and feed rate fluctuations; (2) mid-kiln rings, which occur in the heating-up and calcination zones, are presumed due to high sulfur/sodium content; and (3) front-kiln rings,

which form near the burner, result from overheating of the refractory surface.

The mid-kiln rings pose the major problem in modern kilns. The mechanism of their formation is unclear, although sulfur appears to play a role. This problem is more persistent in kilns which burn NCG, and many mills now scrub their NCG with white liquor to remove sulfur before the gas enters the kiln. The presence of free lime, which can recarbonate in the heating-up zone, is also known to promote ring formation. Thus, high dust recycle could be a factor.

Effect of feed mud solids content

Modern kilns are equipped with oversized precoat type mud filters which deliver lime mud cake in the 70–80% solids (30–20% moisture content) range. The kiln fuel requirements are related to the solids content; the greater the mud cake solids content, the lower the fuel requirements. A heat consumption of about 1200 Btu can be assigned for each pound of water entering with the mud. The installation of oversized lime mud filters in the 1980s has been a major factor in the industry-wide improvement in lime kiln fuel economy from the 9–10 million Btu per ton of kiln product to below 7 million Btu per ton of kiln product.

Merely increasing the feed cake solids, however, does not automatically raise kiln fuel efficiency. Kilns are provided with a chain systems at the feed end to assist in the evaporation of water and to act as a dust curtain. Chain section length and quantity of chains are related to the feed mud moisture content. A smaller chain section is required as mud cake dryness increases without compromising the role of the chains as a dust curtain. *Table 8.5* shows relative fuel usages at different dryness levels.

Table 8.5. Relative kiln fuel usage at different mud dryness levels

| Lime mud dryness | 70% | 75% | 80% |
|---|-------------------------|-------------------------|-------------------------|
| Exit gas temperature* | 315°F | 325°F | 350°F |
| Millions of BTU/ton product (natural gas fuel) | 6.25 (1736 kgCal/kg) | 5.88 (1633 kgCal/kg) | 5.61 (1578 kgCal/kg) |

*Note how exit gas temperatures rise as dryness in feed increases.

Gas flow through the kiln

Gas leaving the feed end of the kiln is the combined total of combustion products, carbon dioxide gas released during calcination, water vapor evaporated from the mud feed, and entrained dust. Natural gas or fuel oil is burned with air, which is supplied by a separate, dampered primary air fan. Primary air, normally 10–20% of the total air requirements, is introduced through a concentric tube surrounding the fuel pipe in the burner and is mixed with the fuel at the firing end of the burner. Preheated secondary air at about 600°F (315°C) is induced through the bottom of the firing

hood or provided in part by a secondary air fan. The fan also keeps the nose ring segments and nose brick cool. When integral tube coolers are used, preheated secondary air is induced and the product from the kiln is cooled to about 350°F (177°C).

Dusting occurs in all lime kilns owing to lime mud dust formation and sodium fume generation. Factors such as mud cake dryness, chain section length, and feed end design influence lime dust formation. Most of the dust generated is lime mud dust from the colder end of the kiln. Lime mud dust is efficiently recovered in a wet scrubber or electrostatic precipitator.

Alkali dust formation results from vaporization of the low-melting-point sodium compounds in the burning zone. The entrained alkali vapor condenses to a fine submicron particle (10 microns or less) when the flue gas is cooled as it proceeds towards the kiln exit. Alkali dust in a kiln feeding well-washed mud will make up less than 3% of the total dust.

A wet scrubber captures a significant portion of alkali fume, but the submicron particles are more efficiently removed in an electrostatic precipitator. The dust collected is recycled and represents a process inefficiency; the dust recycle is typically 10–20% of the incoming feed mud. Figure 8.5 shows the impact of dust recycle on reburned lime production in a kiln equipped with a scrubber.

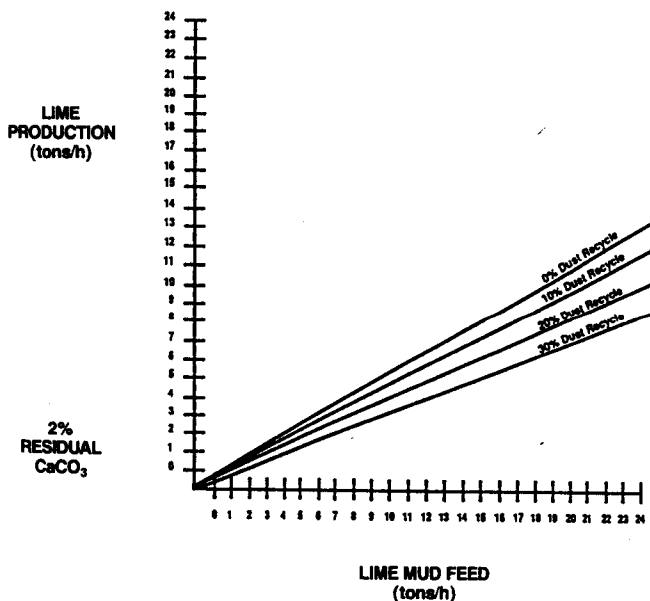


Fig. 8.5. Lime kiln dust recycle impact

Kiln fuels

Natural or manufactured gas, fuel oil, pitch, or pulverized low-ash coke are used to fuel lime kilns (see Table 8.6).

Table 8.6. Typical fuel analyses

| #2 Oil | | #6 Oil | |
|------------------|--------------|------------------|--------------|
| C | 87.2 | C | 85.6 |
| H | 12.5 | H | 9.7 |
| N | ... | N | 1.0 |
| O | ... | O | 1.0 |
| H ₂ O | ... | H ₂ O | .28 |
| Ash | ... | Ash | .12 |
| S | .3 | A | 2.3 |
| HHV | 19430 BTU/lb | HHV | 18300 BTU/lb |
| LHV | 18267 BTU/lb | LHV | 17395 BTU/lb |

| Natural gas | |
|-------------------------------|---------------|
| CH ₄ | 84.1 (Vol. %) |
| C ₂ H ₆ | 6.7 |
| CO ₂ | .8 |
| N ₂ | 8.4 |
| Lb/scf | .04822 |
| HHV | 974 BTU/scf |
| | 20160 BTU/lb |
| LHV | 18224 BTU/lb |

| Analysis (dry basis) % by weight | Delayed coke | | Fluid coke | |
|-------------------------------------|--------------|--------|------------|--------|
| Proximate | | | | |
| Volatile matter | 10.8 | 9.0 | 6.0 | 6.7 |
| Fixed carbon | 88.5 | 90.9 | 93.7 | 93.2 |
| Ash | 0.7 | 0.1 | 0.3 | 0.1 |
| Ultimate | | | | |
| Sulfur | 9.9 | 1.5 | 4.7 | 5.7 |
| Heating value, BTU/lb | 14,700 | 15,700 | 14,160 | 14,290 |

Natural gas and No. 6 fuel oil are the most widely used. A mill will burn the least-expensive fuel available at a given time. No. 6 oil is a heavy oil that contains high levels of sulfur (2% or more). In some areas, stringent kiln sulfur emission standards will require a mill to use more expensive fuel oil with lower sulfur content (0.5%). The heated oil is fired under pressure, and steam typically is used for atomization.

Natural gas is delivered by commercial pipelines. The gas supply may be interrupted, so a standby fuel oil system is required. Most mills report that the maximum production from their kiln is reduced by about 5% after a switch to natural gas from fuel oil. This occurs because the natural gas flame is cooler and more combustion gases are produced than when firing with fuel oil.

In the last decade, rising fuel oil and natural gas prices have prompted mills to look at cheaper alternatives such as wood wastes and petroleum coke. Many kilns in Scandinavia are using wood wastes. Two kinds of

technology are available to make use of wood wastes: (1) firing dried (less than 2% moisture) and finely pulverized wood residue, which is dried using the flue gases from the kiln and boilers; and (2) firing gas produced from an on-site wood gasifier.

Waste wood utilization has some drawbacks, including higher capital costs for the equipment needed to prepare the fuel. The kiln flame temperature is lower and the gas flow is higher than when employing fuel oil or natural gas. This can have a significant impact on kiln capacity.

Petroleum coke is a solid fuel derived from the heavy residual oils produced from petroleum cracking processes. Two types of petroleum coke—delayed coke and fluid coke—are suitable for firing in lime kilns provided the ash content is low. The coke is pulverized to about 80% passing a 200-mesh sieve size and fired in a kiln with a sustaining fuel such as natural gas or oil.

Pulverized coal is not fired in a lime sludge kiln as is customary in cement and limestone kilns owing to the detrimental effect of silica (SiO_2) in the coal ash. Certain silica compounds are water soluble and will remain in the white liquor after slaking. Coal can be fired in a gas producer (producer gas), and this gas can then be fired in the kiln. Numerous kilns in South Africa are fired with producer gas.

Loading and sizing considerations

Loading factors

A variety of kiln sizes are available for any given production rate. For example, a mill could select a kiln with a larger diameter and relatively short length, or a kiln with a smaller diameter and relatively longer length for the same production. Both kilns would have the same internal volume. The quality of lime produced will depend upon how each kiln is fired and controlled in regard to constant and uniform feed, operating temperature, and kiln speed or retention time.

A general rule of thumb in rating lime kilns is to relate the cubic feet of kiln volume required to make a ton of product. The older design practice was to use about 100 ft^3 of kiln volume inside the refractory lining per ton of product. Such kilns operated in the 95–110 ft^3 /ton of lime range with old style internals. In recent years, when an existing kiln has been retrofitted or a new kiln has been purchased, this volumetric factor has been dropped to 70–80 ft^3 /ton of product.

The reduced volumetric factor is possible primarily because of two factors: (1) new or modernized kilns are fed with a much dryer lime mud cake (70–80% solids content); and (2) these kilns feature many internal heat transfer devices that have greatly improved mixing and heat exchange. These low-energy kilns consume less than 7 million Btu/ton of fuel, and the reduced gas flow permits a reduction in the volumetric factor. Figure 8.6 shows the kiln loading factor as a function of lime mud moisture content.

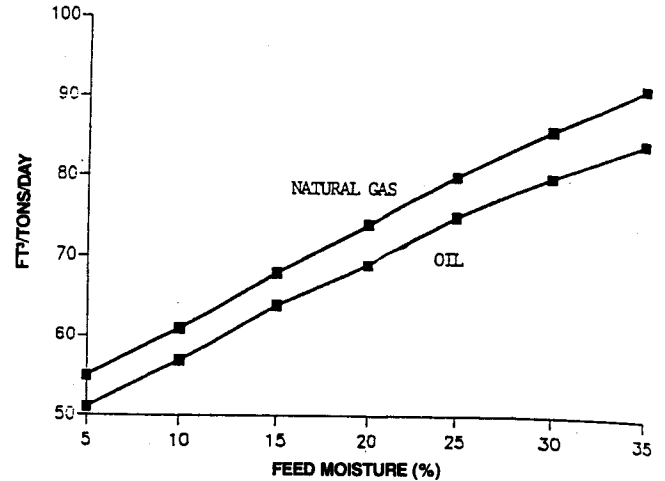


Fig. 8.6. Kiln loading factor (Courtesy Fuller Co.)

Another sizing factor has been the ratio of kiln length to kiln diameter. Many older kilns had a length-to-diameter ratio of 20:1 or lower. With the development of larger and more fuel-efficient kilns, the trend has been toward a length-to-diameter ratio on the order of 30:1–33:1. Cross-sectional loading is another sizing factor. Most modern kilns are designed for a cross-sectional loading of 0.12–0.16 tons/h/ ft^2 based on inside diameter.

Kiln loading factors have been greatly influenced by the design changes made for fuel efficiency. The use of improved chain systems, insulating refractory systems, discharge end dams, and internal mixing devices such as tumblers, lifters, bars, and shields, have all contributed to these advances.

Table 8.7 gives the expected performance from three different proportioned kilns, each with the same nominal rating of 205 tons/day burned product. In this comparison, the feed moisture is taken at 25%, the percent CaO in the product is taken at 90%, and the fuel is Bunker C oil. The improved fuel economy of a kiln with a 30:1 ratio is shown; in this case a 10-ft diam. \times 270-ft long (3.05 m \times 82.3 m) kiln. Larger diameter kilns require less fuel per unit of production than small kilns. Comparative fuel values are shown in Table 8.8.

Table 8.7. Comparative fuel consumptions for equal capacity kilns of different lengths and diameters

| Kiln size (length \times diameter) | Ratio length/ diameter* ratio | Million BTU/ton product (Bunker C Fuel) |
|--|----------------------------------|--|
| 11'-6" \times 195' (3.51 m \times 59.4 m) | 18.5:1 | 6.00 (1667 kgCal/kg) |
| 10'-6" \times 240' (3.2 m \times 73.15 m) | 25:1 | 5.91 (1642 kgCal/kg) |
| 10'-0" \times 270' | 30:1 | 5.88 (1634 kgCal/kg) |

*Diameter inside brick.

NOTE: Kiln rating - 205 TPD; Mud feed - 25% moisture; lime availability - 90%.

Table 8.8. Comparative fuel values for different size and capacity kilns

| Kiln size (length × diameter) | TPD production | Million BTU/ton product |
|-------------------------------------|-------------------|----------------------------|
| 8'-0" × 225' (2.44 m × 68.6 m) | 100 (90.3 MTPD) | 6.08 (1689 kg/al/kg) |
| 10'-0" × 270' (3.05 m × 82.3 m) | 205 (185.9 MTPD) | 5.88 (1634 kgCal/kg) |
| 12'-6" × 330' (3.81 m × 100.6 m) | 415 (376.4 MTPD) | 5.74 (1595 kgCal/kg) |

NOTE: Mud feed - 25% moisture; lime availability - 90%.

Retention time, slope, and speed

Retention time in a kiln is of importance if optimum capacity of a highly reactive product is to be expected. Retention time is determined by kiln slope and speed of rotation. Lime sludge kilns are normally operated at slopes from 1/4–1/2 in./ft, and at rotational speeds from 0.5–1.5 rpm. The slope–speed relationship should be examined to determine the best relationship for each kiln and operation. Proper calcination can be effected if the retention time is between 170 min and 270 min. In order to efficiently transfer more heat to the material, it is necessary to create a rolling or cascading load action rather than a sliding motion. In designing kilns, the rotational speed must be high enough to establish the desirable load action. A high kiln speed (greater than 1.2–1.5 rpm) can create excessive dusting in the chain and lifter sections. A lower sloped kiln with few internals such as lifters, however, can be operated in the 1.2–1.5 rpm range with minimum dusting.

Retention time is directly proportional to the material's angle of repose and the kiln length, and is inversely proportional to the kiln's inside diameter, rotational speed, and slope. The formula used by the U.S. Bureau of Mines to determine rotational speed at designated retention times explains the relationship among the different variables:

$$N = 1.77 \frac{O}{X L} \frac{S X D X T}{X L}$$

where

- N = Rotational speed, rpm
- O/ = Angle of repose
- L = Length of kiln, ft
- S = Slope in degrees
- D = Diameter inside brick, ft
- T = Retention time, min

The angle of repose for lime mud kilns is taken at 35°.

S for different slopes:

- S = 1.79 at 3/8 in./ft
- S = 2.39 at 1/2 in./ft
- S = 2.98 at 5/8 in./ft

Lime kilns almost without exception now include a high refractory dam that is located just uphill of the ports to the attached tube coolers. This dam holds back the lime

material in the burning zone and increases the retention time in the hottest part of the kiln. Sometimes, mid-kiln dams are also installed to increase retention time. Depending on the height of the discharge dam, the retention time will be increased by 20–30 min. The mid-kiln dams are normally not as high as the discharge dams, and they contribute 10–15 min additional retention time.

Table 8.9 shows the slopes, speeds, and calculated retention times for some recently installed lime kilns. Notably, retention times are higher for kilns with product discharge dams.

Table 8.9. Comparison of kiln speed/slope parameters in kilns of different sizes

| Kiln size | Slope (in./ft) | Normal RPM* | Calculated retention time (min) |
|---------------------------|----------------|-------------|---------------------------------|
| Without Discharge End Dam | | | |
| 11.0' × 300' | 3/8 | 1.2 | 153.9 |
| 12.5' × 380' | 7/16 | 1.1 | 157.3 |
| 13.0' × 375' | 7/16 | 1.1 | 148.5 |
| 15.0' × 440' | 7/16 | 1.1 | 148.5 |
| With Discharge End Dam | | | |
| 11'-2" × 295' | 5/16 | 1.2 | 270 |
| 14'-9" × 426' | 5/16 | 1.2 | 270 |
| 14' × 380' | 5/16 | 1.1 | 219 |
| 11'-6" × 325' | 5/16 | 1.2 | 247 |
| 12'-6" × 350' | 3/8 | 1.2 | 180 |

*All new kilns utilize a variable speed motor, and the operator can change the speed and select a suitable retention time.

Lime production process equipment

Figure 8.7 shows a modern lime sludge kiln arrangement. The various components are characterized with respect to their location in the process as follows:

- Feed end or back end
 - mud stage pumps
 - vacuum pumps
 - mud filter
 - agitator drive
 - feed bin and feeder
 - induced draft fan
 - stack
 - main lime screw or conveyor
 - mud filter discharge drive
 - scrubber
- Body
 - steel body shell
 - tires
 - drive motor
 - girth gear
 - auxiliary drive
 - bricks

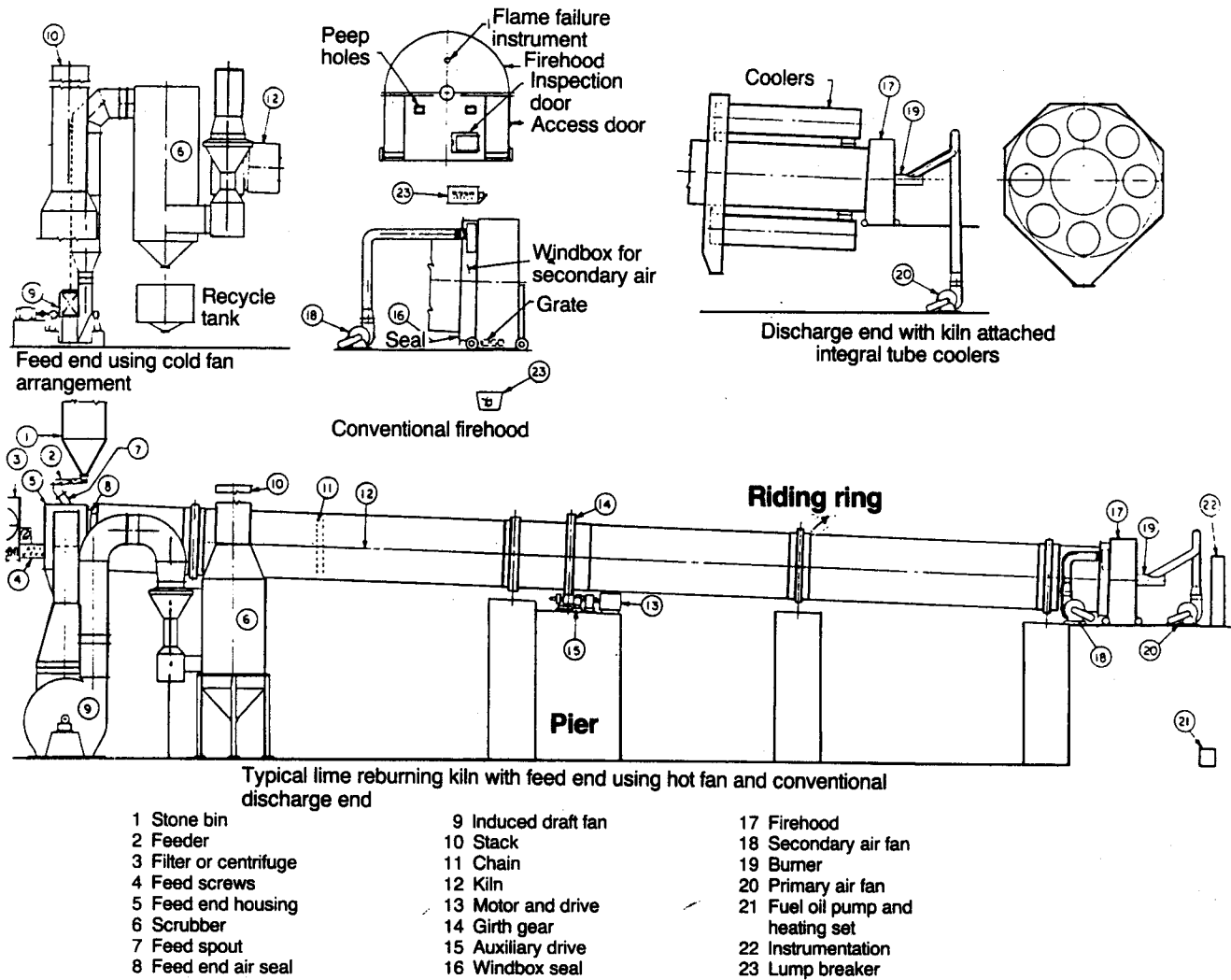


Fig. 8.7. Lime sludge kiln and various arrangements

- chains
- lifter/tumbler
- dams
- Discharge end or hot end
 - lime crusher
 - hot lime pan conveyor
 - pan conveyor drive motor
 - primary air fan
 - secondary air fan
 - fire hood
 - burner
 - fuel oil/natural gas supply system
 - control panels.

Kiln drive

The main kiln drive (see Fig. 8.7 and Fig. 8.8) is located next to the thrust riding ring. The drive maintains a proper relationship between the main girth gear and the driving pinion, regardless of the magnitude of the expansion or contraction of the kiln shell. The pinion gear is mounted to a low-speed shaft of the gear reducer. Most newer kilns are

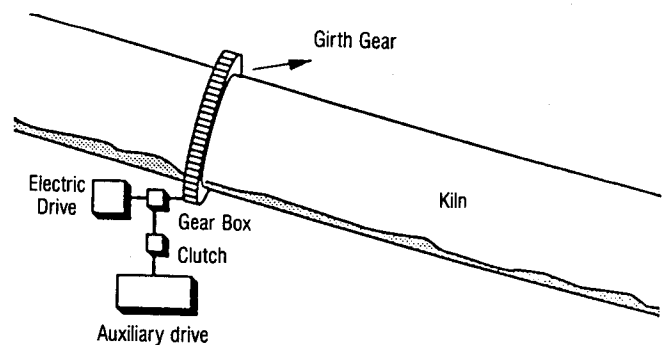


Fig. 8.8. Kiln auxiliary drive, drive gear, and clutch (Courtesy Termorak, Inc.)

turned by adjustable-speed drives. A variable-speed motor is coupled to the high-speed shaft of the gear reducer. The large gear unit is lubricated continuously by an oiling pinion, or by spraying a steady stream of grease onto the gear. Kiln rotation can be varied between 0.5 rpm and 3.0 rpm. Kiln speed is a useful operating variable that

determines the retention time for the lime inside the kiln; retention time controls kiln throughput and the degree of calcination.

An auxiliary drive using a gasoline, diesel, or natural gas engine is required to turn the kiln in the event of an electrical power failure. Kiln manufacturers recommend that auxiliary drives be started every day they are available as a general maintenance check.

During an outage or shutdown, a kiln should not be allowed to cool without rotation, as the kiln shell will warp if a hot kiln containing a hot load is not rotated. Rotation during downtime also relieves the contraction forces on the support rollers. The kiln should be rotated for about an hour, until cool. The rotation can be done at the lowest speed on the main motor drive or on the auxiliary drive.

Kiln supports and thrust mechanism

The kiln is supported on three or four piers. Metal riding rings surround the kiln at these piers, and each riding ring rests on two support rollers. Lubricated bearings allow the support rollers to turn as the kiln and riding rings rotate.

The kiln's downward slope from the feed end to the firing end creates a force that makes the kiln tend to slide down toward the firing end. The support rollers are adjusted periodically to counter this force and keep the kiln in place. In addition, a thrust mechanism is provided at the riding ring located closest to the kiln drive to hold the kiln in the proper position on the support rollers. The thrust mechanism consists of two bevel-faced, cast steel rollers mounted on either side of the riding ring. When the kiln is rotating, the thrust riding ring is either in continuous contact with the downhill thrust roller or floating between the uphill and downhill thrust roller.

The alternate means of controlling thrust is to use a single roller with an optional hydraulic mechanism. In this arrangement, one thrust roller is installed on the downhill side of the thrust riding ring, the support rollers are installed in parallel on each pier, and limit switches are installed to control the movement of the thrust roller. *Figure 8.9A* and *Fig. 8.9B* illustrate a typical double thrust roller assembly and kiln adjustment with a double thrust mechanism, respectively.

The kiln must be properly aligned so that all rollers are adjusted identically. Improperly adjusted rollers cause abnormally high wear on both rollers and tires.

Mud feed systems

The advent of precoat mud filters that dewater mud to 75–85% solids has brought about alternatives to transporting dewatered mud to the kiln feed end. Three systems now in use are the screw conveyor, belt feeder, and combination belt feeder/short screw. *Figure 8.10A* and *Fig. 8.10B* illustrate the screw feeder and belt feeder systems, respectively.

Spiral screw conveyors have been used to deliver 60–75% solids mud cake to the kiln, but the power consumption

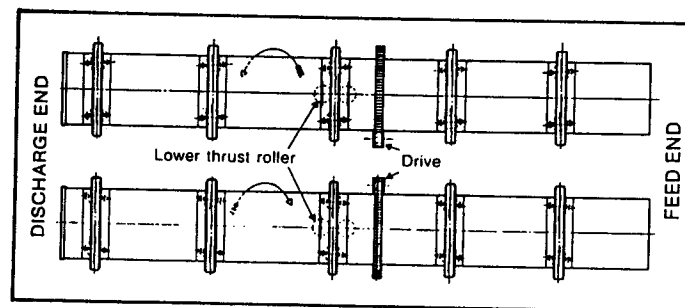
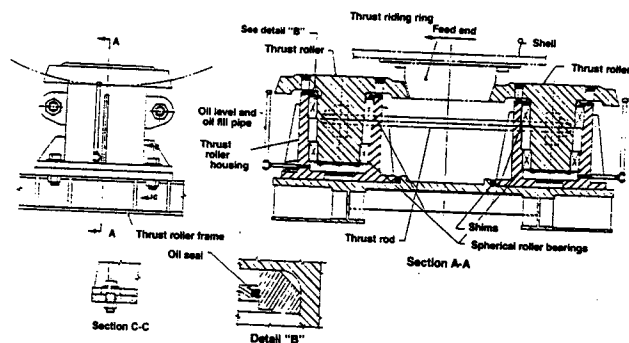


Fig. 8.9. (A) Double roller thrust mechanism and (B) kiln adjustment. (Courtesy Fuller Co.)

increases sharply when the solids content exceeds 70% and the screws are subject to plugging due to the stickiness of the mud. The conveyor and trough are made of carbon steel. A water-cooled jacket is used for the conveyor section extending into the kiln.

Since the mid-1980s, belt feeders have emerged as an alternative to the feed screw. These systems have several advantages, notably that the high power consumption and plugging associated with screws are avoided with a belt feeder. The belts are retractable, and they require less maintenance. However, air leakage into the feed housing is a problem with some belt feeders. Various types of curtain air seals have been employed to minimize this tramp air leakage. The belt conveyor has to be kept free of lime mud dust by frequently washing it with a water hose, or with a compressed air "air knife." Some systems are provided with a drip pan underneath the belt to catch filter cake spillage.

Recently, many new kilns have been furnished with a combination system in which a stationary belt conveyor drops the mud cake from the precoat filter onto a short, larger-diameter heavy-duty screw that delivers the mud to the kiln. For example, short screws ranging from 18-in. to 26-in. (0.5–0.7 m) in diameter would replace regularly sized 10-in. to 18-in. [0.25–0.5 m] diam. screw conveyors. This so-called oversizing prevents plugging, minimizes power consumption, and minimizes problems with poor air seal and housekeeping—in short, minimizes the problems associated with both screws and belts.

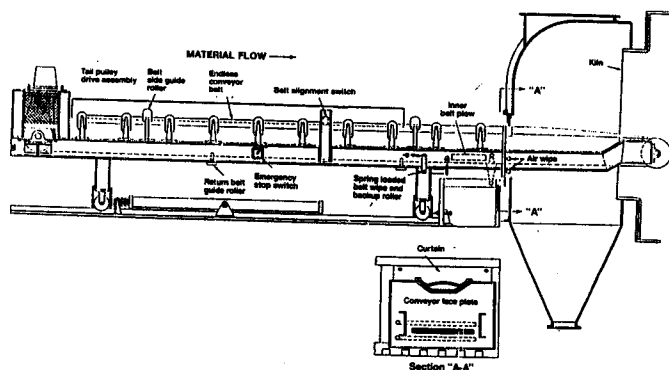
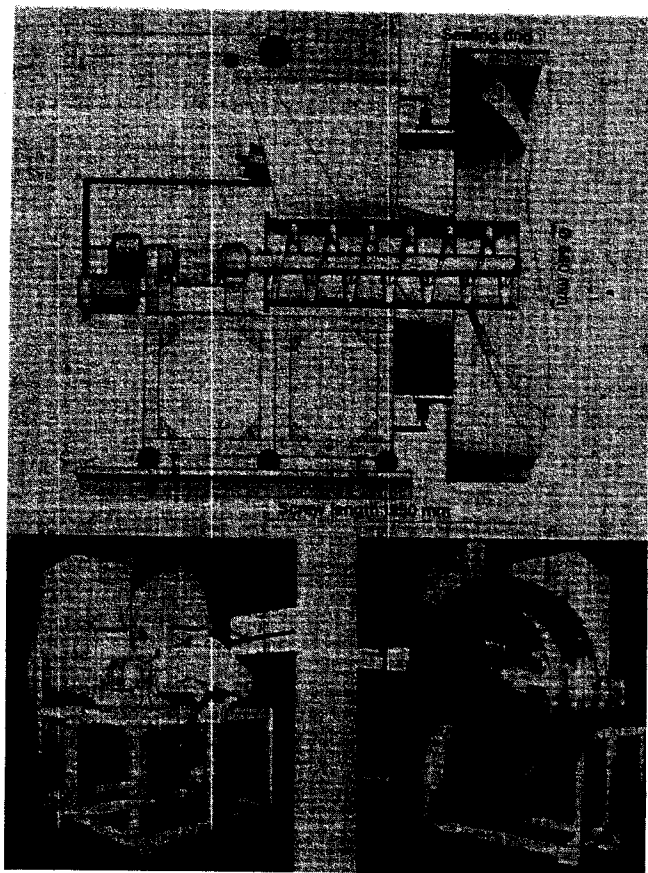


Fig. 8.10. (A) Screw feeder and (B) belt feeder. (Courtesy Ahlstrom Recovery and Boliden Allis)

Feed housing and seals

The feed end housing is a stationary structure providing a connection to the rotating kiln shell for removing exhaust gases and introducing lime mud sludge. A seal is provided to reduce air infiltration at this point. The air seal often rides on a reduced diameter section of kiln shell, which decreases the area for air induction. The reduced diameter assists in eliminating backspill of raw materials into the exhaust gas system. Feed end spirals are also necessary to further eliminate any tendency of the kiln to backspill. A close-fitting seal must be maintained in order to reduce air

utilization and reduce power demands on the induced draft (ID) fan.

The seals in many kilns are floating designs that are restricted in space and often quite inaccessible, and consequently are ignored from a maintenance point of view. Eventually they wear to the point where leakage at the kiln feed end in the seal area can be easily observed.

This leakage is cold, ambient air entering into the kiln exhaust gas system that tends to overload the induced draft fan and restrict the fan from handling additional process gas. In addition, this leakage can fool the operator with regard to the true kiln exit gas temperature and oxygen level. Because the air being introduced at the feed end depresses the temperature before the total gas stream gets to the ID fan, the operator will get false information about the true exit gas temperature if the thermocouple is near the ID fan.

A recent approach to minimizing this leakage is the use of a "fish scale" (or "leaf") seal, which fits against the bulk head of the kiln at the feed end. The seal maintains contact with the kiln as the kiln floats uphill and downhill between the thrust rollers, and as it expands or contracts due to shell temperature changes. Figure 8.11 illustrates how this seal design can be used at the discharge end.

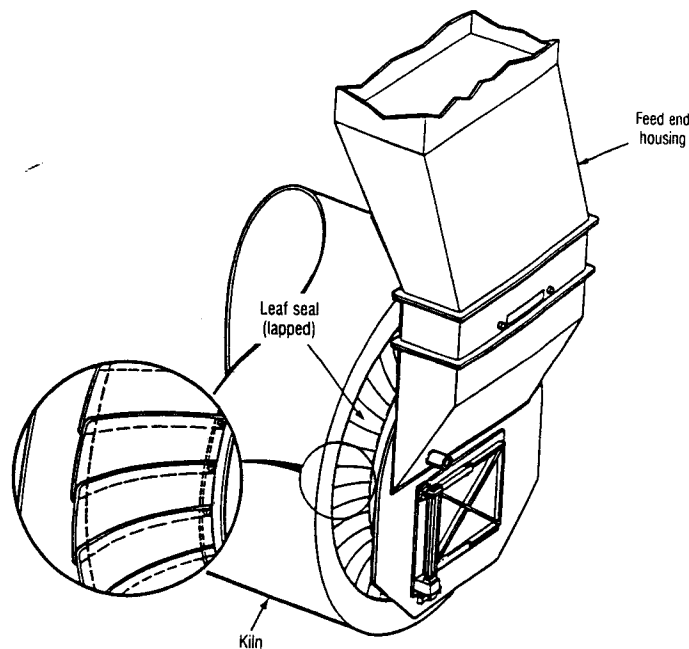


Fig. 8.11. Kiln feed end assembly (Courtesy Boliden Allis)

Induced draft fan

The induced draft (ID) fan in the kiln exhaust system is required to create a draft and to provide static pressure for the dust collector. The fan is referred to as "wet" or "dry," depending on where it is located.

The "wet" (or "cold") fan is located between the scrubber and the stack, as shown in Fig. 8.12. The fan's name is derived from its handling of water-saturated exhaust gases.

Even though the exhaust gases are quite clean at this point, there will be some buildup on the impeller due to the wetness of the gas. Water spray nozzles are used to clean the rotor during operation and thus prevent vibrations caused by the buildup. The rotor and casing are fabricated of stainless steel to minimize corrosion.

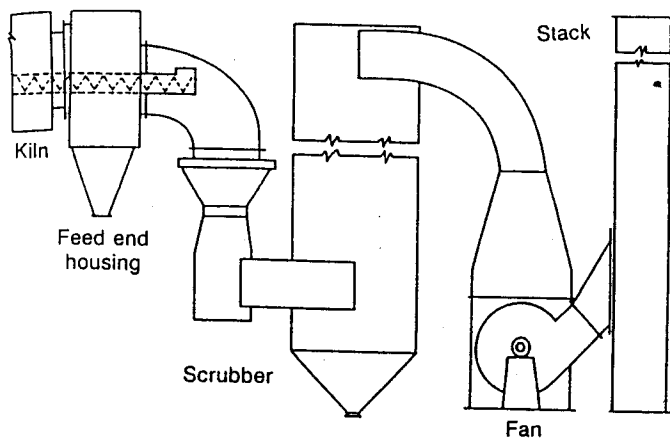


Fig. 8.12. Cold induced draft fan arrangement (Courtesy Boliden Allis)

The "dry" (or "hot") ID fan is located in the hot gas system ahead of the scrubber (or electrostatic precipitator) and handles the hot gases leaving the kiln. *Figure 8.13* shows an arrangement with a scrubber. A dry fan will have a larger capacity than a wet fan for the same size kiln because of the higher gas volume at the higher temperature. The dry fan is not subject to buildup, and it can be fabricated of carbon steel. It may require a water-cooled bearing, however, and it also requires 20% more power than the wet fan. The dry fan has been preferred in most new kilns because it has fewer maintenance problems and lower capital cost.

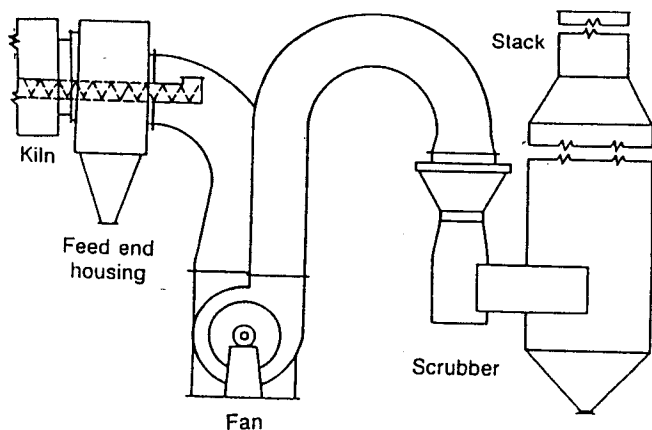


Fig. 8.13. Hot induced draft fan arrangement (Courtesy Boliden Allis)

Either type of ID fan must be of heavy duty construction to minimize downtime. Most fans are equipped with variable speed drives to give the operator better control. The fan must be of adequate size with respect to volume and static pressure in order to foster maximum efficiency of the dust collector.

Kiln lining

Almost all new kilns and many older ones now have insulated refractory systems installed inside the kiln shell. Many insulated refractory systems are available, and they have largely proven that shell temperatures and heat loss can be lowered drastically. In general, an insulated refractory system will reduce fuel consumption by approximately 500,000–600,000 Btu/ton of product compared to the older, conventional 6-in.-thick alumina refractory that was used for many years.

Table 8.10 offers a comparison of the shell temperatures on two 10-ft × 250-ft lime kilns. The older kiln had conventional 6-in. alumina refractory; the newer kiln had a two-layer insulated brick lining. A significant drop in heat loss through the shell by radiation was observed in the kiln featuring insulated refractory lining. From a process standpoint, this reduces kiln fuel usage which then translates into reduced flue gas flow, less potential for dust entrainment, and greater ID fan capacity. These improvements contribute to increasing the kiln throughput.

Table 8.10. Comparisons of shell temperature profiles for two 10' × 250' lime recovery kilns

| | Newer kiln (2 layer insulated brick lining) | Older kiln (6" alumina brick) |
|---|---|-------------------------------------|
| Temperatures: °F | | |
| No. 1 pier | 330 | 680 |
| No. 2 pier | 300 | 565 |
| No. 3 pier | 230 | 340 |
| No. 4 pier | 180 | 260 |
| Average shell temperature | 260 | 461.25 |
| Heat loss: BTU/hr/sq. ft | | |
| Heat loss (vertical) | 468 | 1476 |
| Heat loss (horizontal) facing upward | 516 | 1592 |
| Heat loss (horizontal) facing downward | 409 | 1327 |
| Average heat loss | 464 | 1465 |

Popular insulated refractory systems are dual-brick lined systems, single-brick lined systems, and castable refractory systems. In the dual-brick lined system, an insulating block is installed next to the shell and a refractory brick is placed on top of the insulation. The insulated block and the working lining refractory brick must be properly installed to avoid any rubbing action between the insulated block and the refractory top brick. The insulating blocks are normally softer than the refractory top brick and any movement between the insulation and the brick will abrade or wear the insulation, which will cause the refractory brick to become loose, lose its arch, and fall out.

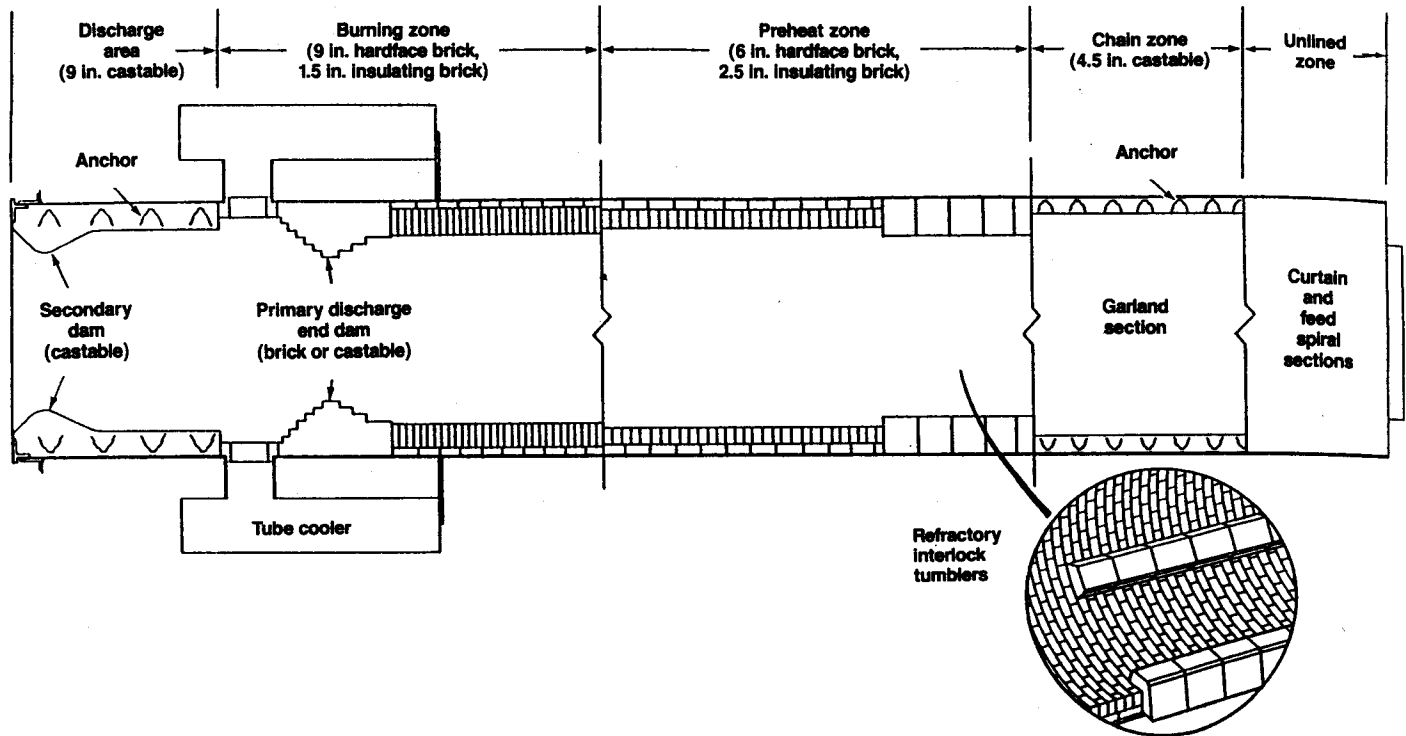


Fig. 8.14. Typical kiln refractory lining
(Courtesy Boliden Allis)

A refractory lining arrangement featuring a dual brick system is shown in Fig. 8.14. Typically, a dual lining comprises 2.5-in. thick insulating brick with a 6-in. hardface fire clay brick (40–60% alumina content) in the kiln preheat zone. In the burning zone, the lining is usually 1.5-in. thick insulating and 9-in. hardface firebrick (60–70% alumina content).

A good firebrick should have low porosity and good thermal shock and chemical resistance. Table 8.11 displays properties of a high-alumina firebrick. Low alumina content gives inadequate service temperature and high alumina content increases the risk of chemical attack. Lower alumina content bricks, however, have better insulating properties. Generally, 40–70% alumina content appears to optimize both requirements.

Table 8.11. Physical data of selected refractories

| | K factor | Maximum service temp. °F | Silica (%) | Alumina (%) | Bulk density PCF | Cold crush strength PSI | Porosity (%) | Linear shrinkage (%) | |
|---------------------|----------|--------------------------|------------|-------------|------------------|-------------------------|--------------|----------------------|------|
| 70% alumina* | 11.7 @ | 2400°F | 3300 | 23–27 | 68–72 | 160 | 5000 | 20 | -4 |
| 40% alumina* | 8.8 @ | 1200°F | 3000 | 50 | 45 | 145 | 4000 | 15 | -1 |
| 60% alumina* | 10.3 @ | 2400°F | 3200 | 37 | 59 | 157 | 6000 | 15 | 1 |
| Superduty firebrick | 8.9 @ | 1200°F | 3000 | 53 | 42 | 148 | 4500 | 10–13 | -0.6 |
| Insulation brick | 1.67 @ | 750°F | 1750 | 79 | 12 | 51 | 2030 | 65 | 1 |
| | 1.95 @ | 1200°F | | | | | | | |

A variety of insulating bricks are in use. A good insulating brick should exhibit high crushing strength (2000–2500 lb/in.²) and insulating capacity (1.45 Btu/ft²·h·°F).

An efficient insulating brick is relatively soft, raising concerns about its integrity among kiln operators. If not properly secured, the softer insulating layer can erode and cause the hardface brick to loosen and drop out. This is particularly true if the heat-up and cool-down schedules are not carefully controlled. The softer brick will be exposed to the high temperatures in the kiln which will cause the brick to melt down. A properly installed dual layer system will

eliminate any relative motion between the insulating layer and the hardface when the hot kiln is rotating.

The inset in *Fig. 8.14* shows one approach to securing the dual lining with tumblers. In some systems, the tumblers are anchored to the shell by welding. *Figure 8.15* shows some of the currently available brick systems. A dual-layer brick system, particularly one with tumblers, is more difficult to install and repair than single-layer brick work. To overcome this problem, composite type two-layer bricks and single-layer lightweight insulating bricks have been introduced. These bricks combine the requirements for a hardface lining with good insulating properties. Current experience with these single-brick insulating refractory systems is limited, and their initial costs tend to be higher.

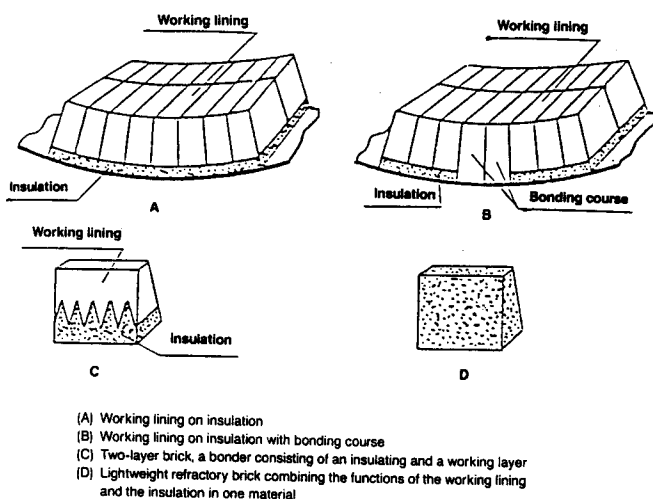


Fig. 8.15. Types of insulating lining
(Courtesy Refratechnik GmbH)

Castable refractories resistant to abrasion and chemicals and suitable for high temperature service may also be used to line a kiln. The available types of insulated castable refractory systems all use an insulated block or brick next to the kiln shell with a high-temperature, castable refractory working lining. One system (see *Fig. 8.16*) requires that stainless steel anchors be welded to the inside of the shell on about 9-in. (22.9 cm) centers. A high-quality insulated mineral wool block with holes cut into the block is installed next to the inside diameter of the shell. The castable refractory is then installed over the mineral wool block, then vibrated into the holes in the block around the stainless steel anchors to secure the working lining castable to the shell. Outside shell temperature of only 245°F (118°C) have been observed when the brick hot face temperature was over 2000°F (1093°C) in a typical castable refractory lined system. In general, insulated castable linings are more expensive and require longer installation time than insulated dual-brick systems.

Newly installed refractory linings or repaired linings must be thoroughly dried before the kiln is started. The linings can be dried by keeping a small fire in the kiln for about

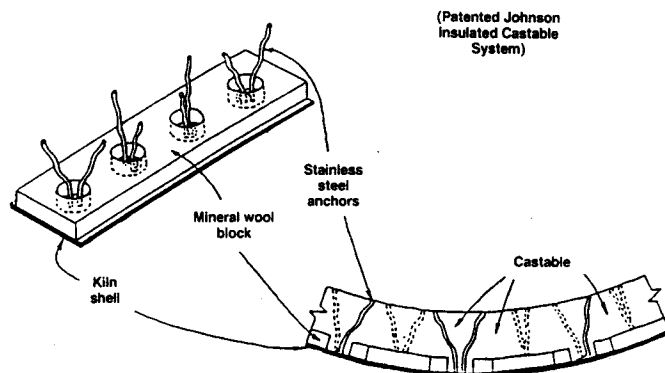


Fig. 8.16. Insulated castable refractory system
(Courtesy Fuller Co.)

48 h; during this period, the kiln should be rotated about 180° every 15 min.

Internal heat transfer devices

Without internal heat exchangers, kiln exhaust gas temperatures would reach 1200°F (648°C). Properly designed internal heat transfer devices will reduce the exhaust gas temperature to the 300–400°F (149–204°C) range. Normally, the heat in the exhaust gas is all lost to the atmosphere. Internal heat exchangers are a necessity for low-fuel consumption, particularly if the kiln is not equipped with an external device such as a flash dryer to recover the heat in the exhaust gas.

Chain systems, dams, tumblers, lifters and bars, and mixing shields are among the heat transfer devices in use. *Figure 8.17* represents typical internal heat transfer devices.

Properly designed internal heat exchange devices (1) should reduce the exhaust gas temperature from the kiln to approximately 300–400°F (149–204°C); (2) should not cause excessive dusting at the feed end of the kiln; and (3) should not retard the flow of the feed through the kiln to the extent that it falls out the feed end (backspill to the feed end housing).

Chain Systems

Most kilns employ chains in the feed end (wet end) of the kiln to dry and preheat the wet mud. When the kiln rotates, the chains dip into the wet mud and are lifted out. On rotation, the solids coating the chains dry and fall free of the chains, which can then absorb heat from the hot gases to repeat the cycle. A properly designed chain system will dry and preheat the mud feed and recover a large quantity of the heat in the exhaust gases before the gases leave the kiln. Typical temperatures of the kiln gases are 1200–1400°F (649–760°C) at the discharge end of the chain section. The temperature of the gases after they leave the feed end fall to 300–400°F (149–204°C), thereby reducing the dust recycle and fuel consumption. This in turn reduces the kiln exhaust gas flow to the I.D. fan and dust collector, offering an opportunity to raise the kiln production rate.

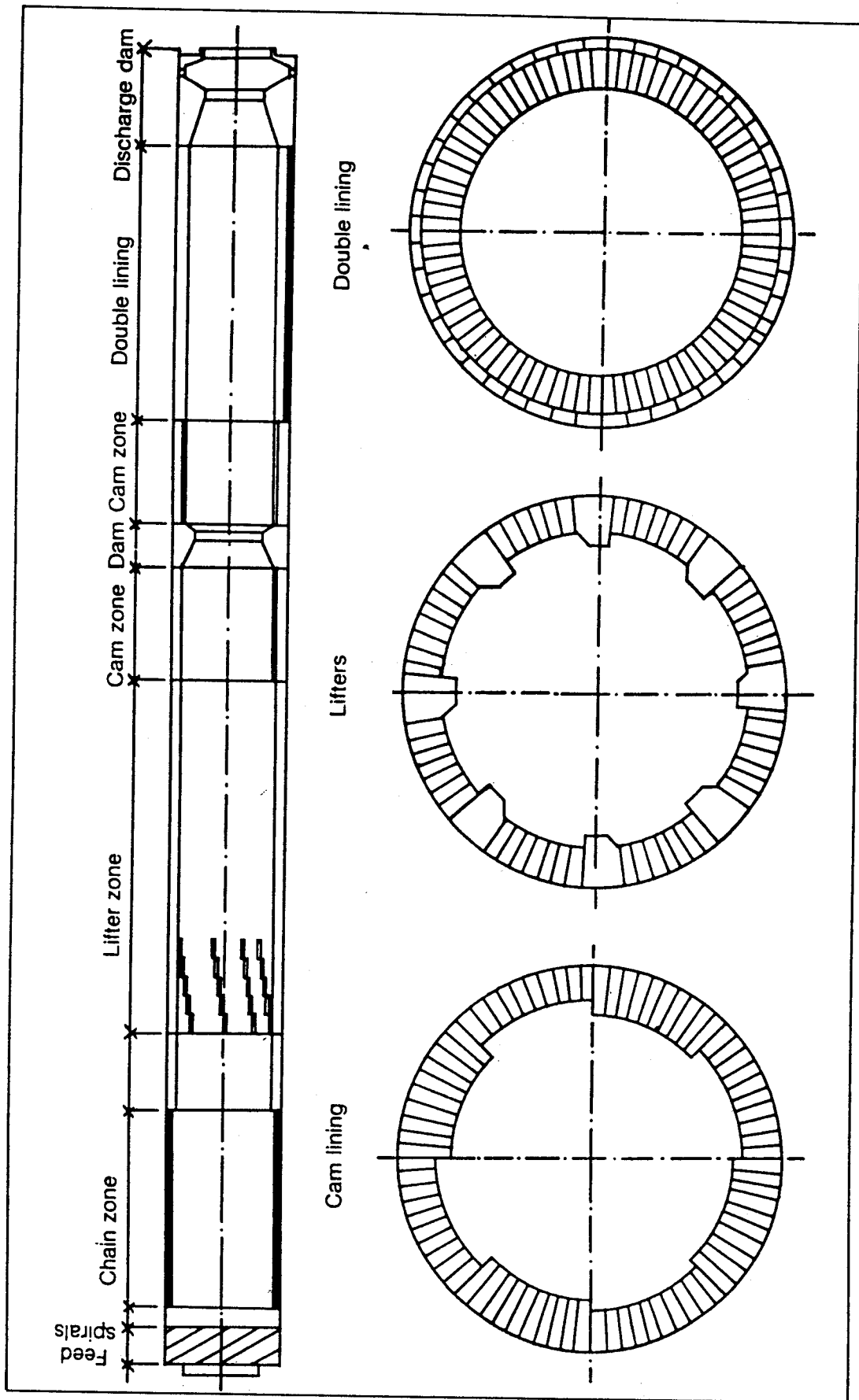


Fig. 8.17. Typical lime kiln internals

Suppliers offer several types of chain systems. Generally, the weight of the chains determines how much heat energy is transferred up the lime kiln from the burner, and the surface area of the chains determines how fast energy is transferred to the lime mud to evaporate water.

In recent years, high-density chain systems with the capability to accomplish complete drying of the mud to zero moisture, preheat the dried mud in an extended-chain section, and suppress dust carryover have been installed in many kilns. Some concerns have been raised whether such high-density systems are not more prone to more dusting if the kiln were turned down to rates that differed from the design.

Most chain systems have a short feed spiral section (usually about 1–1.5 times the kiln diameter in length) to move the wet mud cake forward as it enters the chains. Chains typically are attached to the kiln shell with hanger bars and shackles. Alternatives are to attach the chains in a straight hanging pattern where only one end of the chain strand is fastened to the shell, or in a double-hung loop system, where the two ends of the chain are fastened to the shell. Different chain hanging systems are shown in Fig. 8.18 and Fig. 8.19 illustrates a chain section.

The first part of a chain system is a section of high density chains, usually straight hung, which act as a dust curtain. The soda content and dryness of the incoming mud influence the amount of chain needed. The second part of the chain section is usually less dense, usually straight hung or in the garland pattern. Most of the mud drying occurs in this part. Garland chains offer the advantages of keeping the kiln lining cleaner and better breakup of mud balls. Chains in both these parts are made of mild steel.

Some systems have a final high density chain system made of stainless steel (or a high temperature alloy) where the mud is preheated to zero moisture content. The dense chains serve to suppress dust carryover that could result from total drying. The chain section is generally lined with a castable refractory lining to minimize heat losses due to radiation and to improve fuel economy.

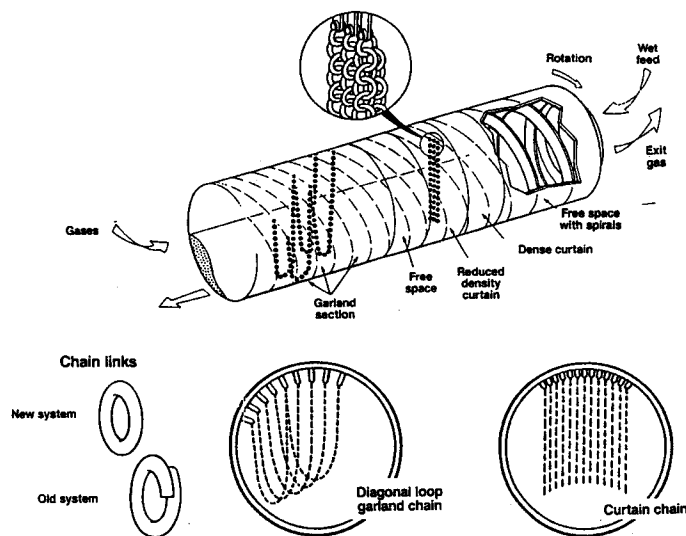


Fig. 8.18. Chain system for lime recovery process (Courtesy Boliden Allis)

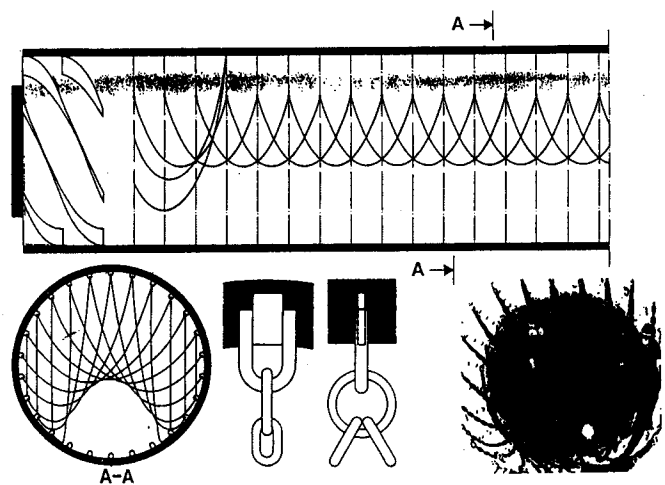
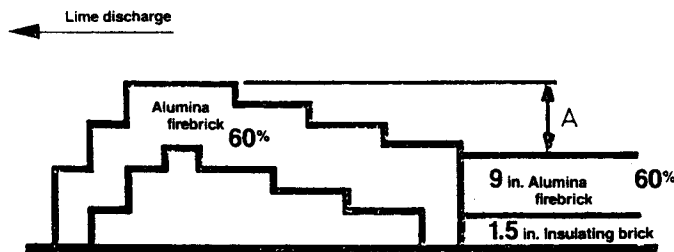


Fig. 8.19. Chain section (Courtesy Boliden Allis)

Discharge end dam

Refractory dams are another important internal heat exchange device. These have been in use in Scandinavia for almost two decades, but in North America, only “low” dams (12–18 in. above the working lining) were used in a few kilns. Since the 1980s, however, dams of the type shown in Fig. 8.20 have been installed in new kilns or in upgraded older kilns. Typical dam heights are shown as a function of kiln diameter.

A discharge end dam is located just uphill of the grates to the tube coolers. The gentle sloping of the dam shown in Fig. 8.20 improves refractory durability and moves a well-mixed lime product gently out of the kiln. The dam increases the retention time and the bed depth of the lime in the burning zone right under the flame. The calcining reaction is time and temperature dependent, and if retention time is increased, then the calcining zone temperature can



| Kiln diameter | | Height of the dam A | |
|---------------|---------|---------------------|---------|
| (ft) | (m) | (in.) | (mm) |
| 7–8.5 | 2.1–2.6 | 12–14 | 300–350 |
| 9–10.5 | 2.7–3.2 | 20–22 | 500–550 |
| 11–12.5 | 3.3–3.8 | 24–26 | 600–650 |
| 13 | 3.9 | 28 | 700 |

Fig. 8.20. Refractory dam and dam dimensions

be reduced and the kiln can be run colder. The increased bed depth means the load is closer to the flame, resulting in fuel savings since the radiant heat transfer from the flame is maximized. Also, lime quality is improved because the heat transfer is more uniform and the tendency for overburning is avoided. Another advantage is improved kiln refractory life owing to the lower calcined lime temperature.

A mid-kiln dam may be installed in the heating-up zone to improve heat transfer between the hot gases and the lime mud. These dams are much lower in height compared to discharge end dams. They increase retention time and smooth the movement of lime down the kiln.

Most dams are built with high alumina (60–70% alumina) brick of the type used in the burning zone. In some kilns, high alumina content brick is used only on the top, hot face of the dam and is backed with low alumina (40%) refractory. Castable dams (using high temperature [2500°F, 1370°C] coarse castable) are also in use.

Tumblers and lifters

Next in importance, after the chain section and discharge end dam, are the tumblers (and other mixers) which immediately follow the chain section. In most kilns, this marks the beginning of the refractory lining. Without a series of tumblers, the refractory lining would be a smooth surface allowing the lime burden to slide on the brick surface as it moves down the kiln; the lime bed would not be turned over, and the top and bottom would be overheated.

Tumblers cause the bed to roll over, promoting uniform heat transfer with the hot gas and increasing the surface area of the lime's contact with the hot gas and with the refractory. Tumblers thus promote greater heat efficiency and product uniformity. Energy savings on the order of 10–15% can perhaps be realized when tumblers are installed in older kilns. The tumbler principle is illustrated in Fig. 8.21.

Typically, tumblers are installed over the entire heating zone following the chain section, covering about 20% of the kiln length. Six to eight evenly spaced tumblers are installed around the inside circumference of the kiln, depending on kiln diameter. In order to minimize dusting, the tumbler action should be gentle, and the tumbler height should not exceed about 6 in. (15 cm) above the refractory lining.

The tumblers in use are the brick tumbler, the castable tumbler/lifter, and steel lifters/bars. Fig. 8.22 illustrates these types.

Brick tumblers have lost popularity in modern kilns because local stresses arise where the brick tumbler contacts the refractory and can cause the refractory to crack, especially at the ends of the longest bricks. Castable tumblers may be precast or cast on-site. Precast tumbler sections anchored to the kiln shell have been preferred in most modern lime kilns, whereas onsite-cast tumblers have been mainly used in kiln rebuilds.

Some new kilns also feature three or four 20-ft-long steel bar sections, placed around the circumference above the refractory lining. These lifters superheat the mud leaving

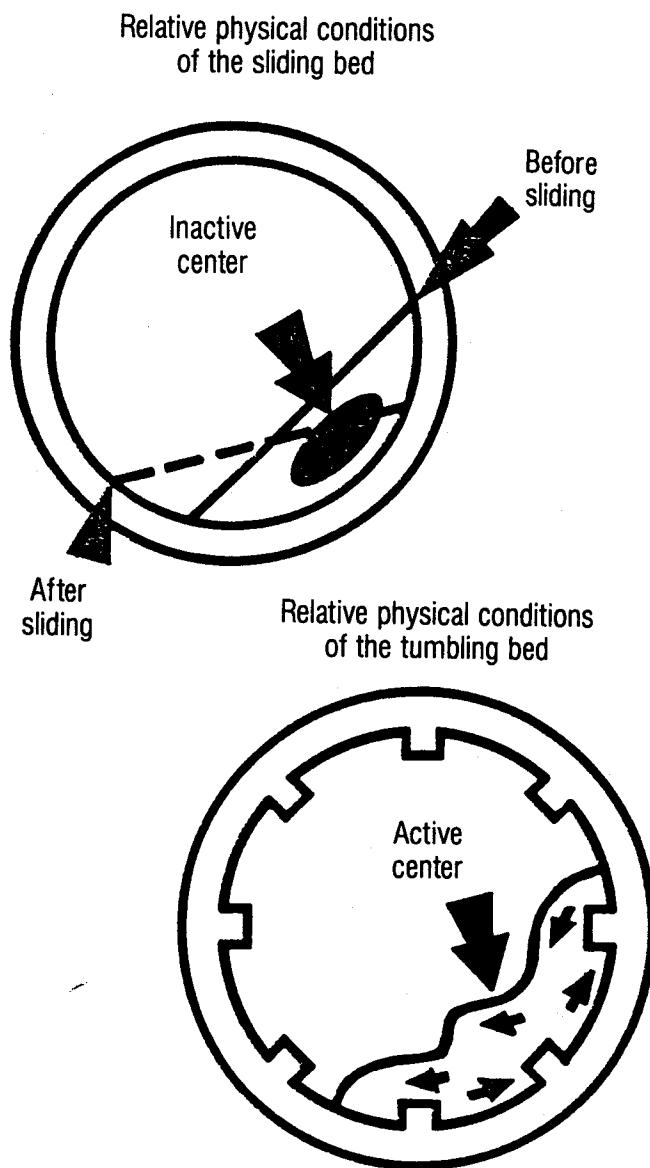


Fig. 8.21. Tumbling action
(Courtesy Ahlstrom Recovery)

the chain section, and have partially replaced chains in some kilns.

Mixing shields

Mixing shields have long been used in cement industry kilns, but are a recent innovation in paper industry kilns. These shields further improve the heat transfer in the heating-up zone by promoting thorough mixing of the lime mud with the hot kiln gases. One to four mixing shields can be installed, which can yield energy savings of 6% to 10%. Figure 8.23 illustrates the gas mixing accomplished with mixing shields.

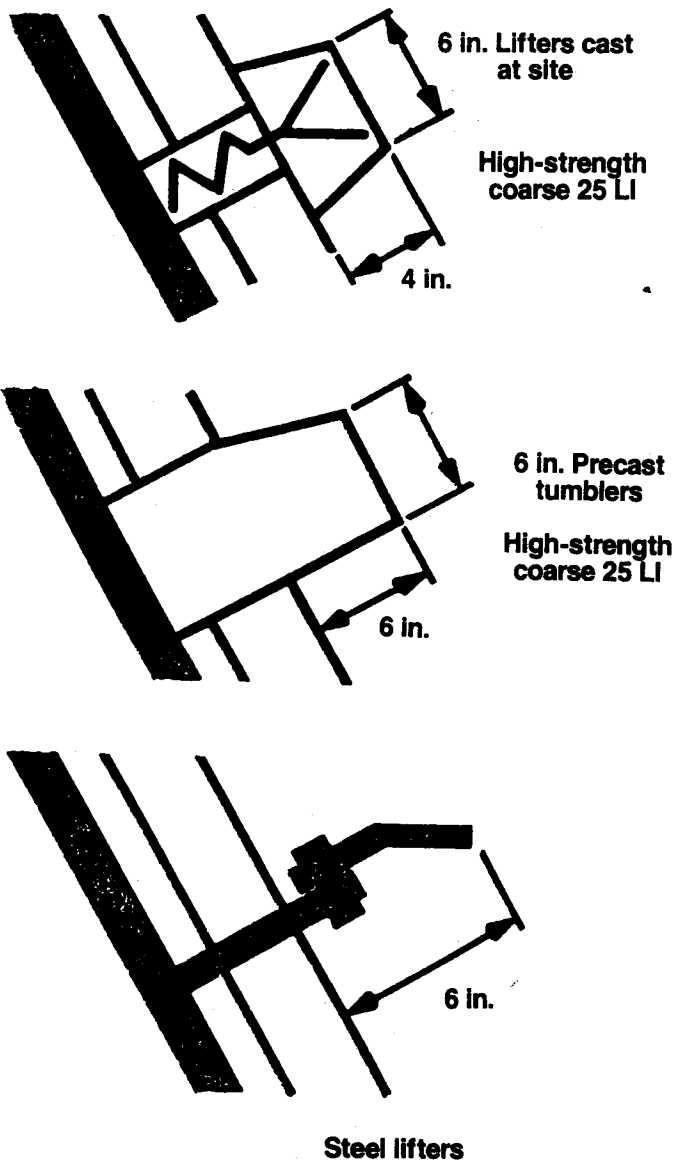


Fig. 8.22. Types of tumblers

Burner

The burner is used to atomize the kiln fuel and mix it with air to form a suitable flame pattern. Figure 8.24 shows a typical combination gas and oil burner arrangement.

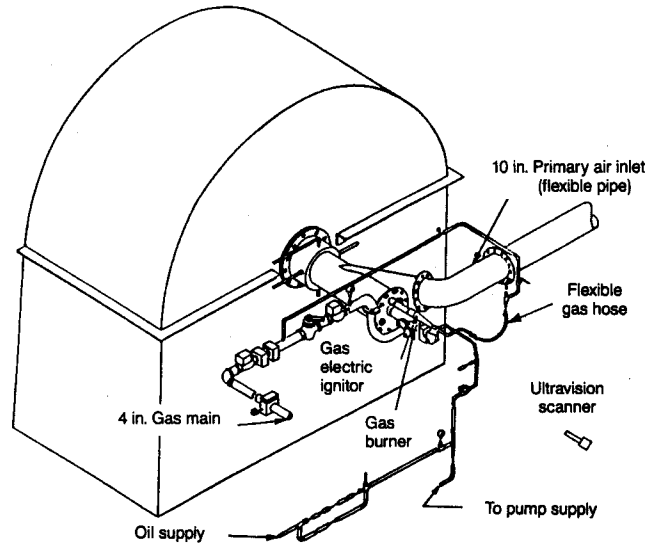


Fig. 8.24. Combination gas and oil burner

Burner selection and the flame characteristics that it produces play an important role in kiln performance with respect to lime throughput, product quality, fuel usage, and refractory life. The major factors influencing flame development are:

- air/fuel mixture
- burner nozzle design and diameter
- primary air/fuel velocity
- primary/secondary air ratio
- excess air
- atomization method
- NCG composition/flow
- product discharge dam.

Mixing shield

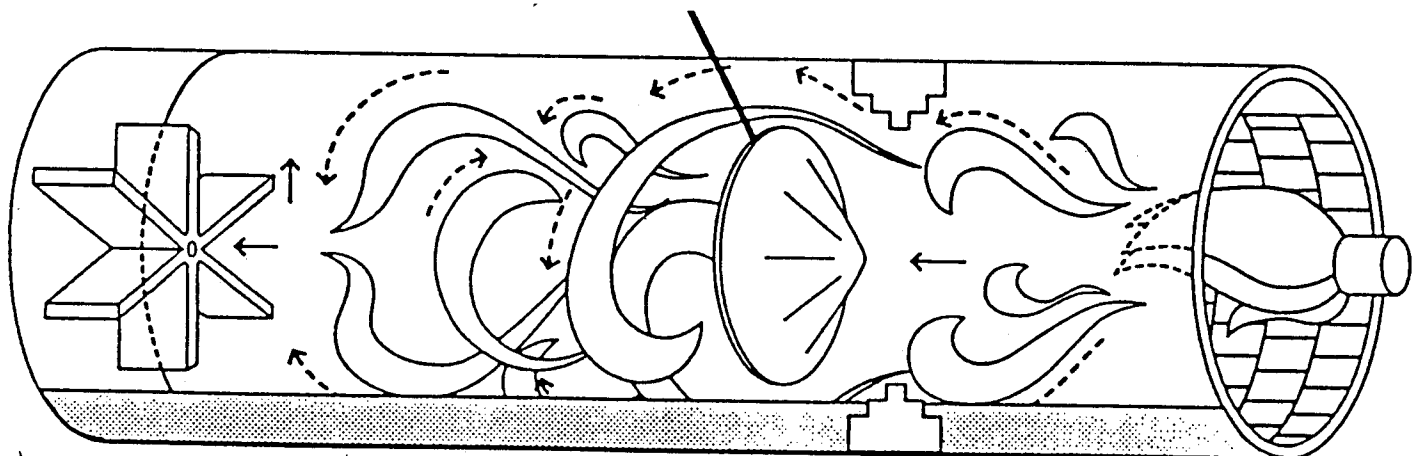


Fig. 8.23. Air mixing created by the mixing shield (Courtesy Termorak, Inc.)

Nozzle diameter, air/fuel mixing, and fuel atomization are the main burner design variables. The bigger the nozzle diameter, the bigger the flame produced. The primary air fan (and secondary air fan when used) must be generously sized to permit the fuel/air ratio to be altered over a wide range. Natural gas is easily atomized in the air/fuel mixture. Oil burners are generally steam atomized, though some designs feature air or mechanical atomization. The fuel oil must be kept heated to 220–250°F (104–121°C) before atomization can be accomplished.

Different flame shapes are illustrated in *Fig. 8.25A*. A high ratio of primary air/fuel compared to secondary air will produce a short, intense, bushy flame. Insufficient primary air will produce a long, lazy flame which can burn in a substoichiometric manner and actually cool the kiln. The relative roles of primary and secondary air are illustrated in *Fig. 8.25B*. Primary air will tend to shorten the flame; high velocity air will shorten the flame further. Uniformly distributed secondary air will make the flame more compact and sweep it away from the refractory lining. Usually, primary air is about 10–15% of total combustion air requirements.

A common problem encountered with some kilns has been the excessive use of primary air, which causes turbulent mixing and a short, intense flame. A short flame has a high temperature, and high radiant heat transfer to the lime load. Although kiln throughput and fuel efficiency will be higher, the short flame will cause lime overburning and can be detrimental to refractory lining life.

In double-brick refractory systems, the overheating of the firebricks heats up the insulating bricks. As a result, the service temperatures of the insulating bricks are exceeded and refractory failures occur. Longer flames exhibit poor heat transfer that causes incomplete lime mud calcination. A tradeoff is a compact flame of medium length (about three times the kiln diameter) that covers about 60–70% of the inside diameter. The flame should not impinge on the refractory, and should gently “lick” the load. Many kilns are now equipped with product end discharge dams that can influence the gas flow pattern shown in *Fig. 8.25B*. The flames can get shorter and hotter, so the preferred position of the burner tip is slightly behind the dam.

Many pulp mills, because of odor emission standards, incinerate noncondensable gases (NCG) collected from the digester and evaporator plant in the lime kiln. Such disposal can pose problems, such as ring formation. The NCG flow can be variable, and it can contain significant amounts of water vapor. Operators have experienced problems maintaining throughput because of the need to keep higher than normal excess oxygen levels in the flue gas for good total reduced sulfur (TRS) control.

Many burner design options address NCG disposal. A key aspect of all designs is that the noncondensable gases are introduced at the root of the burner flame to ensure complete oxidation of all the malodorous sulfur compounds. One approach is to mount a separate pipe or pipes inside the blast pipe of the burner right up to the

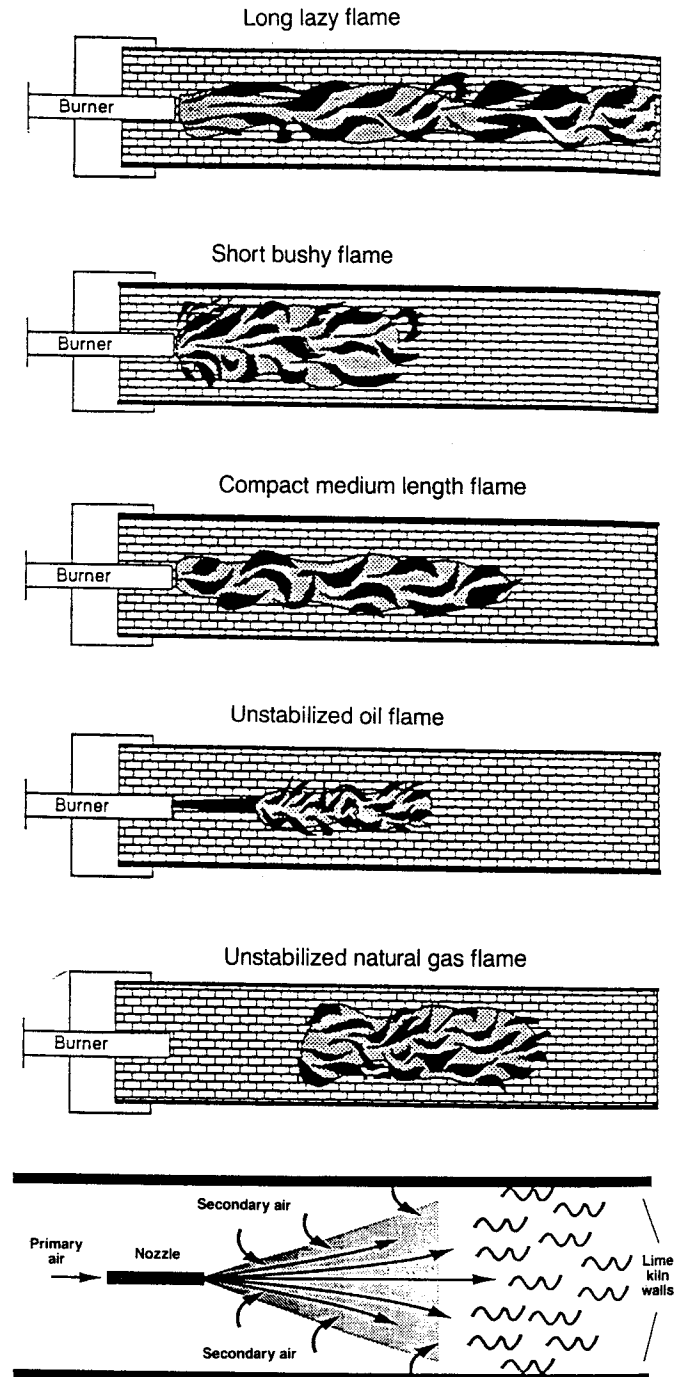


Fig. 8.25. (A) Flame shapes in kilns and (B) pattern of air velocity against inside walls. (Courtesy Termorak, Inc.)

burner tip. The cross-sectional area of the piping will depend on the NCG volume and composition. A second option introduces the NCG in a separate annulus within the primary air tube. In some kilns, the NCG is introduced in a separate pipe (with or without its own primary air fan) oriented to produce a flame that mixes with the main burner flame. This last approach has the advantage of not upsetting the main burner operation.

Firing hood/fire shield

A firing hood (*Fig. 8.26A*) or firing shield (*Fig. 8.26B*) is necessary to close the discharge end of the kiln. The hood or shield should include openings for inspection, instruments, and burner insertion. The hood or shield assembly should include either wheels or an overhead trolley so that it can be withdrawn to allow access to the kiln for major refractory repairs. A split or "barn door" type firing hood design is also in use. The split between the doors is sealed during normal operation. Overhead rails allow the doors to be rolled away to permit access for maintenance.

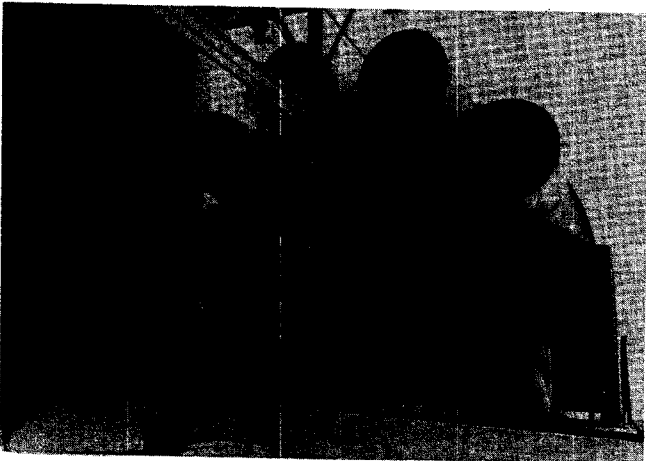
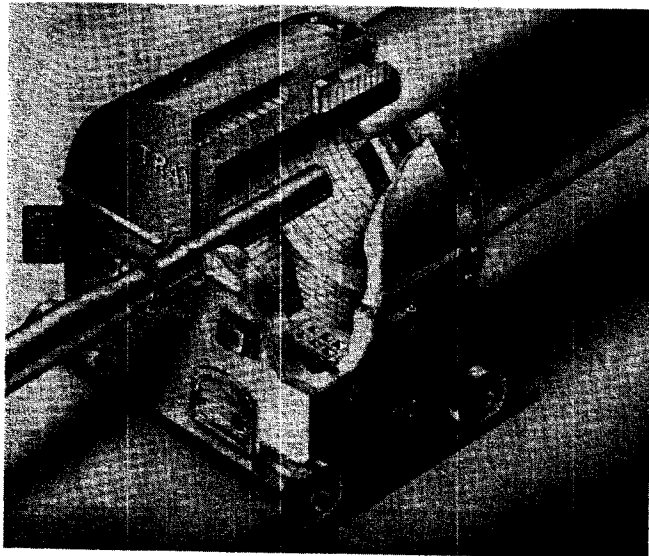


Fig. 8.26. (A) Kiln firing hood and (B) firing shield (Courtesy Boliden Allis)

A firing shield at the discharge end offers lower capital cost than a firing hood, and could help to keep tramp, cold secondary air from entering because the opening for the firing hood discharge is eliminated.

Most lime recovery kilns produce balls and chunks on occasion which, in the case of a firing shield, must exit the kiln via the tube coolers. Typically, kilns with firing shields will have a secondary dam at the extreme discharge end of the kiln to retain the balls and chunks until they break up

or wear down to the point where they can enter the coolers. However, some of these balls and chunks are too hard to break up or wear down, forcing a kiln shutdown to break them up manually. During operation these chunks and lumps grind up the nodulized product, thus aggravating the system dust loss.

A firing hood, on the other hand, will permit the balls and chunks to discharge from the kiln into the hood where they can be directed to a lump breaker, or pulled out if they are too hard to break up. Meanwhile, the kiln continues to operate.

Product coolers

Integral tube coolers are used on all newer kilns, and on some older North American kilns. Secondary air induced through the coolers is preheated while the lime product is cooled to 350–400°F (177–204°C). The energy savings range from 350,000–700,000 Btu/ton of product. *Figure 8.27* shows a kiln with coolers.

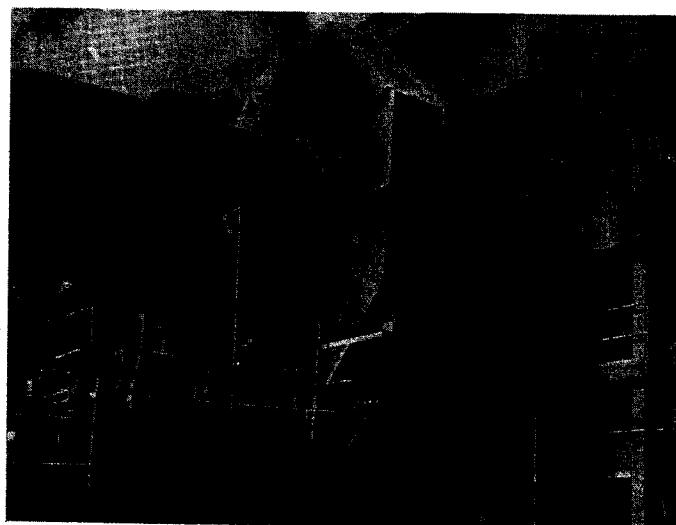
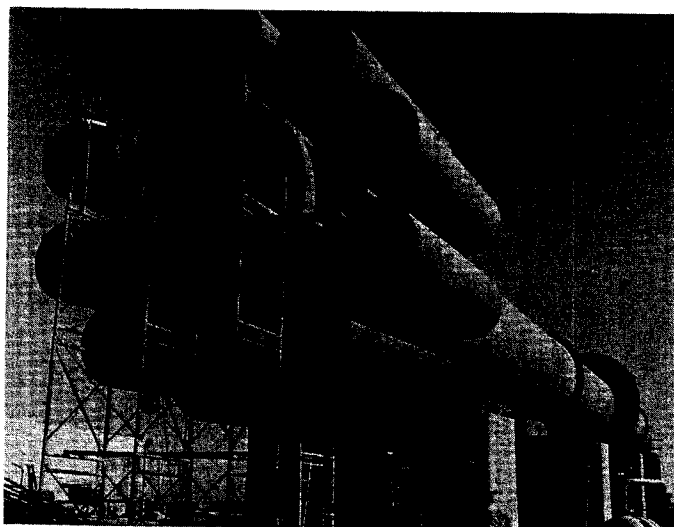


Fig. 8.27 (A) Kiln attached integral tube coolers (Courtesy Fuller Co.) and (B) coolers installed in the plant

The coolers are attached to the discharge end of the kiln in such a way that the calcined lime will fall into the coolers at the extreme discharge end of the kiln. Once in the coolers, the product will reverse direction of flow and be propelled through heat exchanging arrangements uphill to the opposite end of the cooler, where it will have cooled to the desired temperature.

Induced secondary air required by the burner to complete combustion (about 70% of air requirements) enters the coolers through openings at their discharge ends.

This air, in the heat exchange process, is heated to about 600°F (315°C). The heated air then enters the kiln and combines with the fuel and primary air to complete combustion. Such coolers are efficient, returning 75–80% of the heat given up by the lime; the remainder is lost via radiation.

Coolers can be subject to plugging. Designs that assist in the easy flow of the product lime including spiral tube, free flowing, and open screw/conveyor plate. These designs are illustrated in *Fig. 8.28* and *Fig. 8.29*.

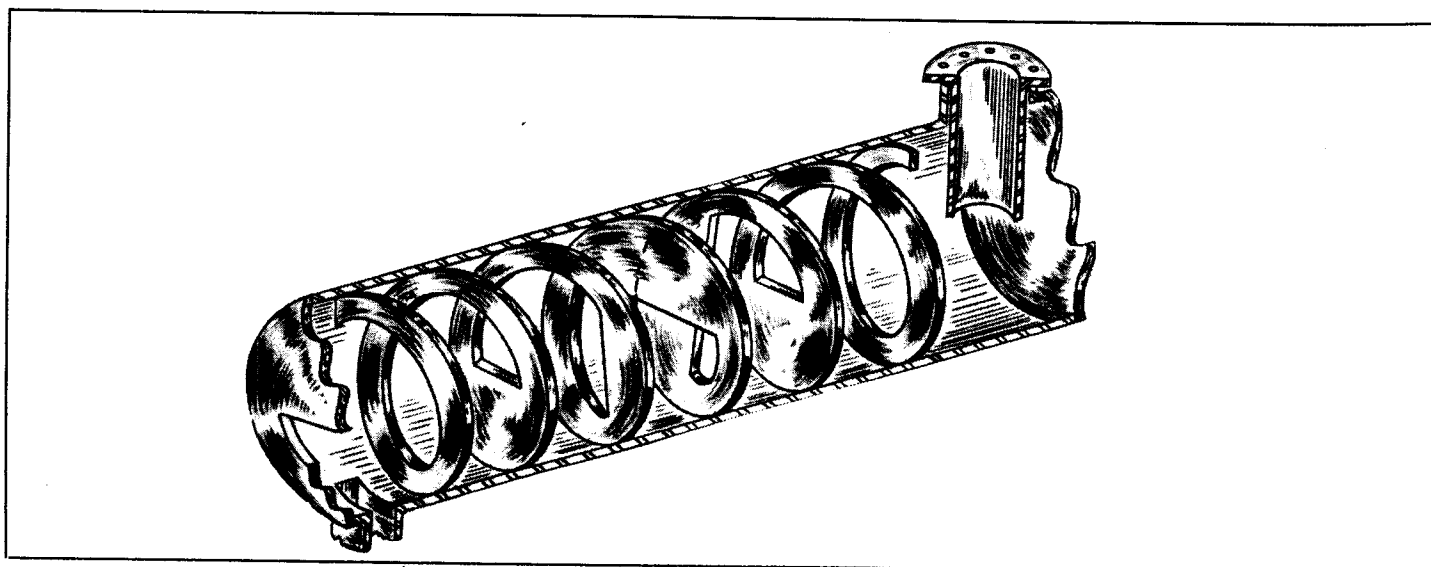
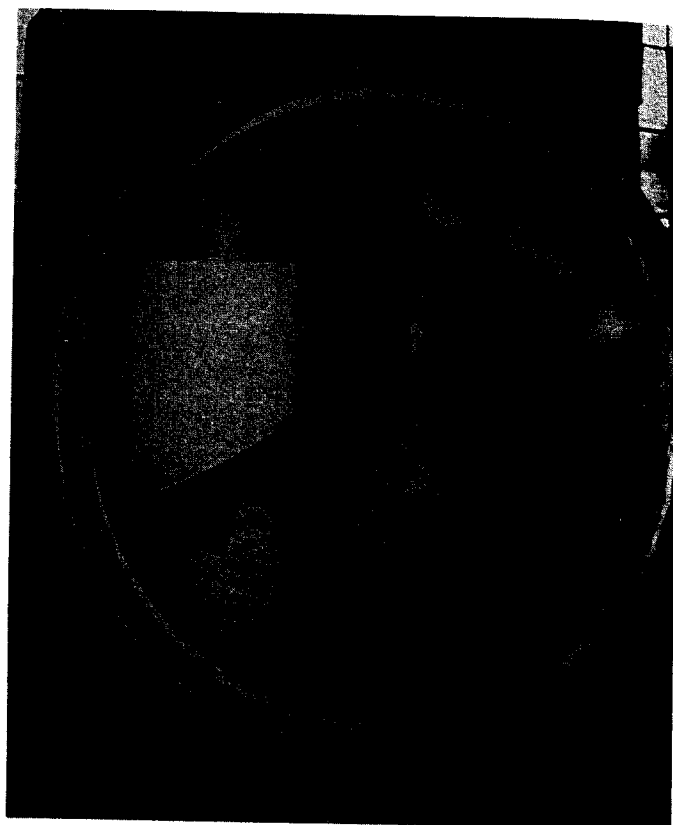
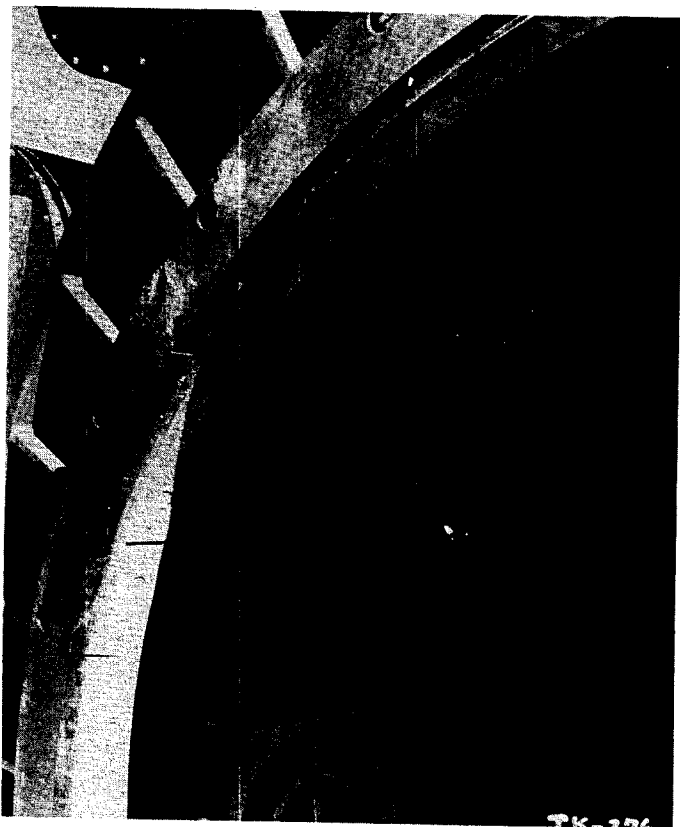


Fig. 8.28. (A) Discharge end of kiln before bricking showing grates at entry to coolers; (B) feed end internal construction of kiln attached integral tube cooler (Courtesy Fuller Co.); (C) spiral attached tube cooler

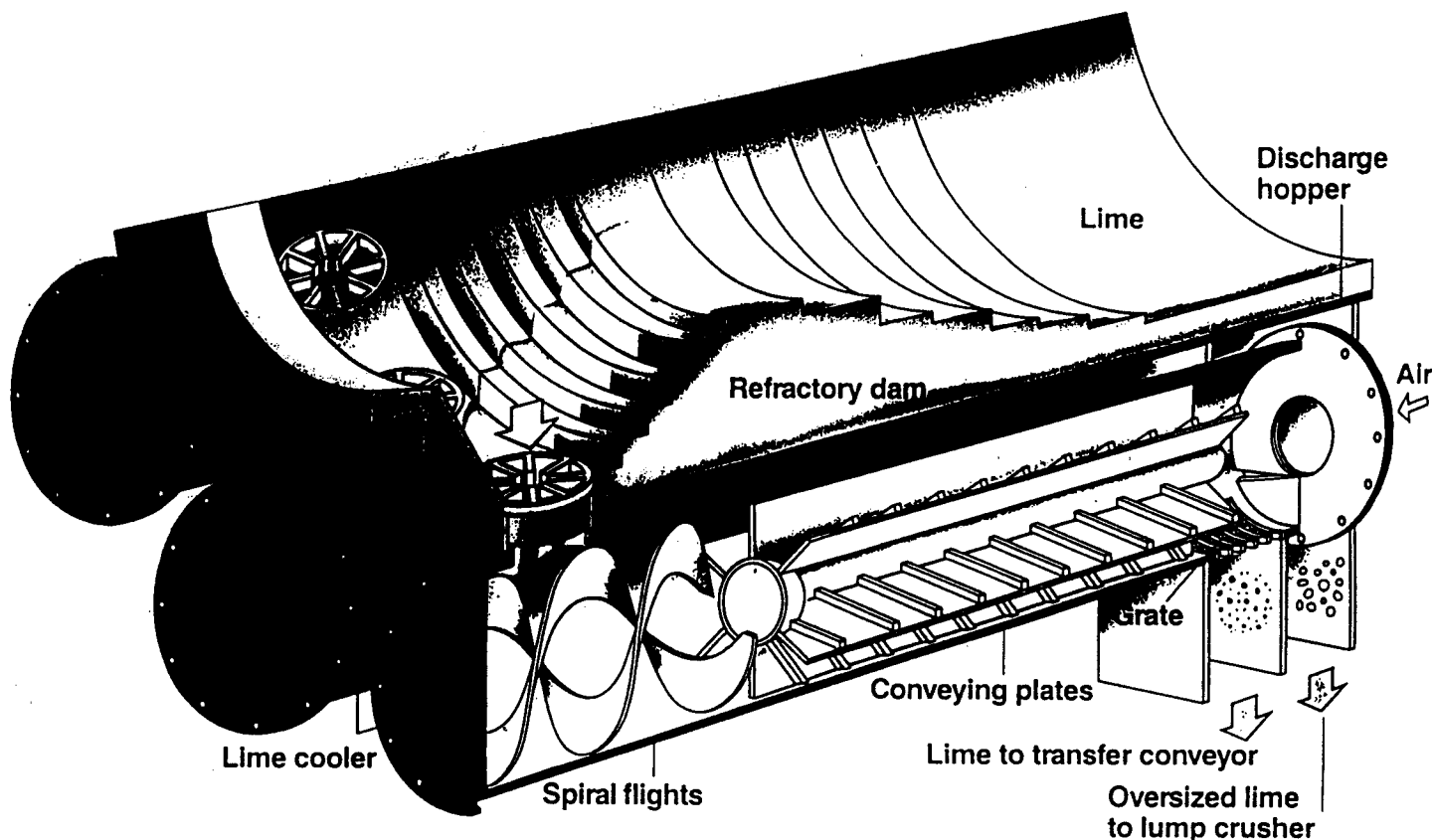


Fig. 8.29. Open screw/conveyor plate cooler design
(Courtesy Ahlstrom Recovery)

A kiln generally has three to 10 cooler tubes, which will vary in diameter from 3–5 ft (1–1.5 m) and in length from 10–20 ft (3–6 m). Coolers are designed for either side discharge or bottom discharge. Heat-resisting grates are constructed to limit the size of the material passing into the coolers at points of material entry.

Auxiliary lime kiln operations

Reburned lime handling

Reburned lime handling systems transport the lime leaving the product coolers (or the kiln discharge hopper if there are no coolers) to the reburned lime storage bin generally located near the slaker. The handling system comprises a hot lime crusher, a hot lime discharge hopper, and a reburn lime conveyor.

Crushers

Lime slakers can usually handle 1–2 in. (25–50 mm) chunks of lime. Protective grizzlies ahead of the hot lime conveyors have been adequate in many mills where the quantity of oversize is nominal. In modern kilns, hot lime crushers (see *Fig. 8.30A*) are often used to eliminate the need to remove and manually break up large lumps.

Crusher units must be rugged enough to cope occasionally with large pieces of kiln lining as well as lime

chunks. The most widely used have a water-cooled hopper, a rotating shaft, and moving cutter blades rotated by a heavy-duty drive train. The fixed and moving teeth are arranged to pass a maximum 2 in. (5 cm) wide piece.

A torque controlled coupling and warning signal can be provided to stop the crusher in the event of an overload of coarse material. It is advantageous to equip the crusher with means for reversing the direction of the blades to reject excessive accumulations of lime. High-speed crushers are not recommended because of the dust nuisance they create.

An alternative to breaking up balls and lumps in a lime sludge kiln without coolers is to install nose ring castings at the discharge end of the kiln to act as an internal lump breaker. These nose ring castings are called discharge end alligators (see *Fig. 8.30B*). These alligators break up large lumps before they discharge into the fire hood. Lumps as large as 3–4 in. (7.6–10 cm) can pass the alligators, so a second lump breaker usually is installed under the grate in the fire hood to reduce the lumps to less than 2 in. (5 cm) before the product discharges to the hot lime conveyor.

Hot lime discharge hopper

A hopper forms a ring around the kiln, providing a cover and seal around the discharge end of the cooler, and extends downward from the kiln to the reburn lime conveyor. The only moving part is a diversion gate which can divert the lime to the ground in the event of a conveyor

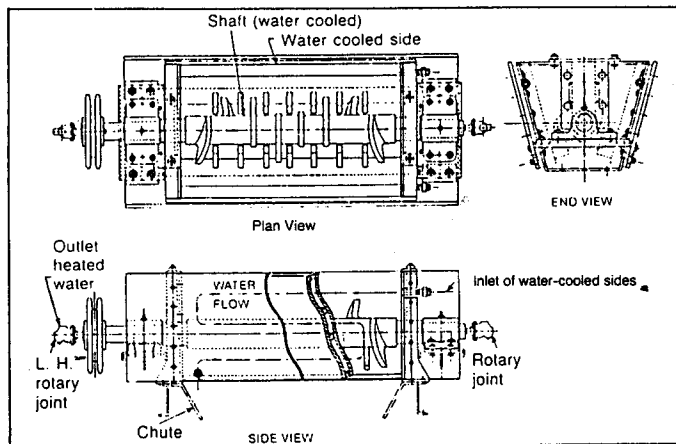


Fig. 30. (A) Hot lime crusher and (B) discharge end alligators. (Courtesy Fuller Co.)

outage. The slight negative pressure in the housing minimizes dusting during lime discharge.

Reburned lime conveyor

Hot lime handling is a demanding function that requires adequately sized and designed equipment. The lime temperature will range from 300–350°F (150–177°C) in kilns with tube coolers, and about 1800–1900°F (980–1040°C) in kilns without coolers. Hot lime conveyors are normally sized to convey three times the average design production of the kiln to allow for surges that can result from hangups in the kiln.

Drag conveyors, oscillating conveyors, pan type conveyors and bucket elevators are all used to transport lime from the kiln discharge to the hot lime storage bin. Drag conveyors are built for heavy duty, and normally have a water-cooled bottom. Water must be kept from leaking into the lime. The conveyor has extra-heavy heavy bottom plates and replaceable wear strips.

Oscillating conveyors are limited in length of transfer to about 50 ft (15 m). They tend to be dusty and require more maintenance than other types.

Pan conveyors are most commonly used because they are rugged, they wear well, they withstand the hot lime temperature, and they require minimum maintenance.

A specially designed lime bin can be used to store both hot lime and fresh lime (see Fig. 8.31). A center tube is used to contain the hot lime, which ranges in density from 60–75 lb/ft³ (900–1200 kg/m³). When the kiln production rate exceeds the slaking rate, the tube fills up and hot lime spills over to the annular space around the tube. When the kiln production rate is less than the slaking rate, the lime around the periphery of the tube feeds along with the hot lime in the tube. The bin is self-compensating, as the material feeds down the center in preference to sliding down the conical bottom. This cone bottom bin is located above and immediately adjacent to the slaker.

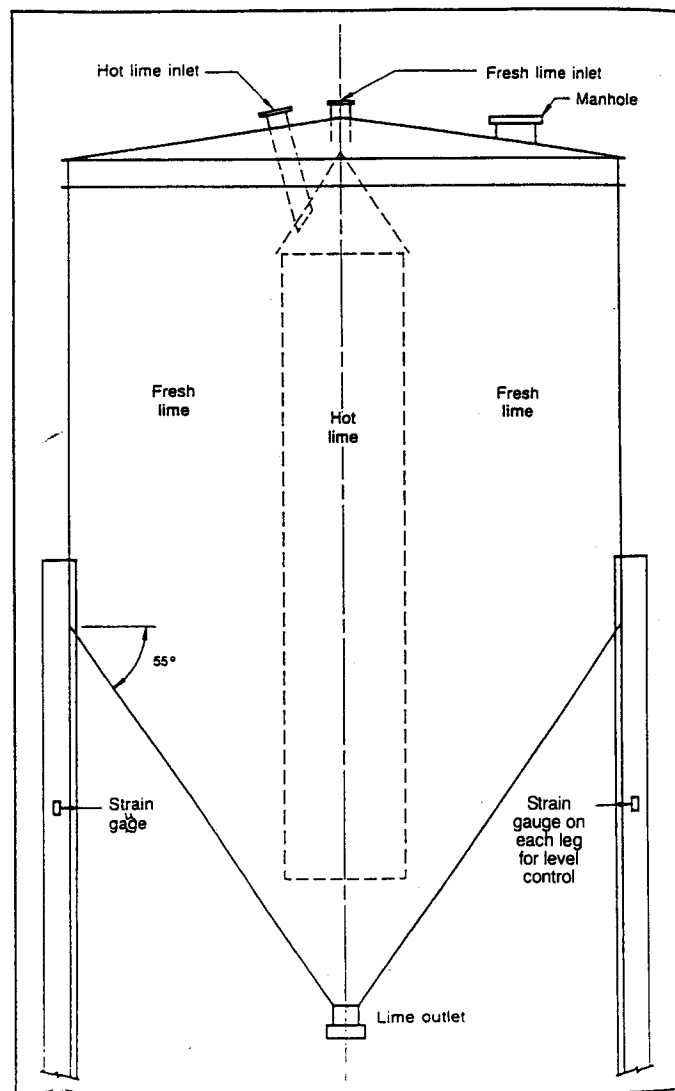


Fig. 8.31. Combination lime bin

Flue gas handling systems

For many years, lime kilns were equipped with different types of scrubbers to capture dust from the kiln exhaust gases before they were released to the atmosphere. These were characterized as "wet" scrubbers because they used water as the scrubbing media. Environmental standards regarding particulate emissions and the release of sulfur dioxide and TRS gases place greater emphasis on flue gas treatment than in the past. Technological advances have included electrostatic precipitators, which have come into increasing use in newer kilns because of their excellent particulate collection efficiency. Systems in use today are venturi type wet scrubbers, electrostatic precipitators, and cyclone separators (used in combination with a scrubber). In some locations, depending on the emission standards, a combination of the above three systems may be used.

Venturi type wet scrubbers

Venturi scrubbers are classified as gas atomized (high pressure drop); ejector atomized (low pressure drop); and air atomized (compressed air). All venturi scrubbers have several common features:

- A sudden expansion from the inlet duct to a larger diameter convergent-divergent cone, with some water introduced to wash the walls of any buildup that may occur. The venturi action takes place at the throat. The pressure drop across the throat of the venturi is commonly used as a measure of scrubbing efficiency.
- Impingement of the high speed slurry into a flooded tank (called elbow tank).
- Introduction of the slurry tangentially into a separator vessel where cyclonic separation of the particulate solids in a liquid slurry is achieved and the clean gas exits.

Figure 8.32 shows the process flow scheme for a gas atomized venturi scrubber, which is the type used in most older North American kilns. Recycled scrubber liquid is delivered to the converging cone section where the flue gas velocity increases, eventually approaching 100,000 ft/min. At these high velocities the flue gas atomizes the scrubber liquid to small droplets that are separated in the separator. The high gas velocities require a high static I.D. fan pressure, which produces a pressure drop of 20–30 in. of water across the venturi throat. These units are also called high pressure drop scrubbers.

Figure 8.33 shows the process scheme for an ejector atomized venturi scrubber. This type of unit was developed because the older gas atomized systems were inefficient in meeting new emission standards. Ejector atomized venturi scrubbers, also called low pressure drop scrubbers, have been in use in Scandinavia for over a decade. Scrubbing liquid is pressurized to 300 psig and atomized in an ejector nozzle at the venturi throat. The ejector also induces the gas flow and thereby reduces fan power requirements. The pressure drop across the venturi is only 5 in. of water. The pressurized scrubbing liquid can plug the nozzles, so a small clarifier is incorporated in the scrubber liquid recycle

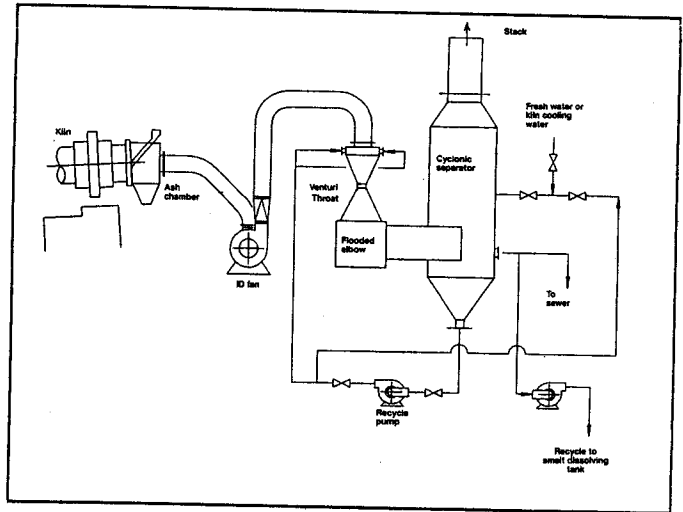


Fig. 8.32. Gas atomized venturi scrubber (Courtesy Fuller Co.)

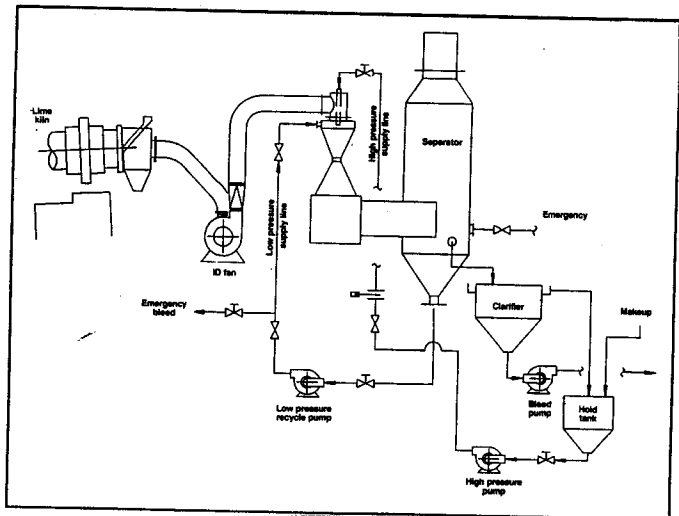


Fig. 8.33. Ejector atomized venturi scrubber (Courtesy Fuller Co.)

to remove the lime particles. These units have performed satisfactorily, except when the dust recycle in the kiln became excessive.

The air atomized scrubber, shown in Fig. 8.34, is a recent innovation that uses compressed air, flowing countercurrent to the incoming gas, to atomize the scrubbing liquid. The liquid is not pressurized, and the pressure drop ranges from 13–15 in. of water. The smaller pressure drop of the ejector and air atomized units show overall power savings compared to the older high pressure drop units. The wetted parts in a scrubber should be made of stainless steel to minimize corrosion by sulfur dioxide. In some scrubbing systems a small amount of caustic soda (or, soda ash) is added to the scrubber water to enhance removal of sulfur dioxide. Scrubbing can also produce some reduction in TRS gases, but the best way to minimize TRS emissions is to reduce mud sulfide content in the kiln mud feed.

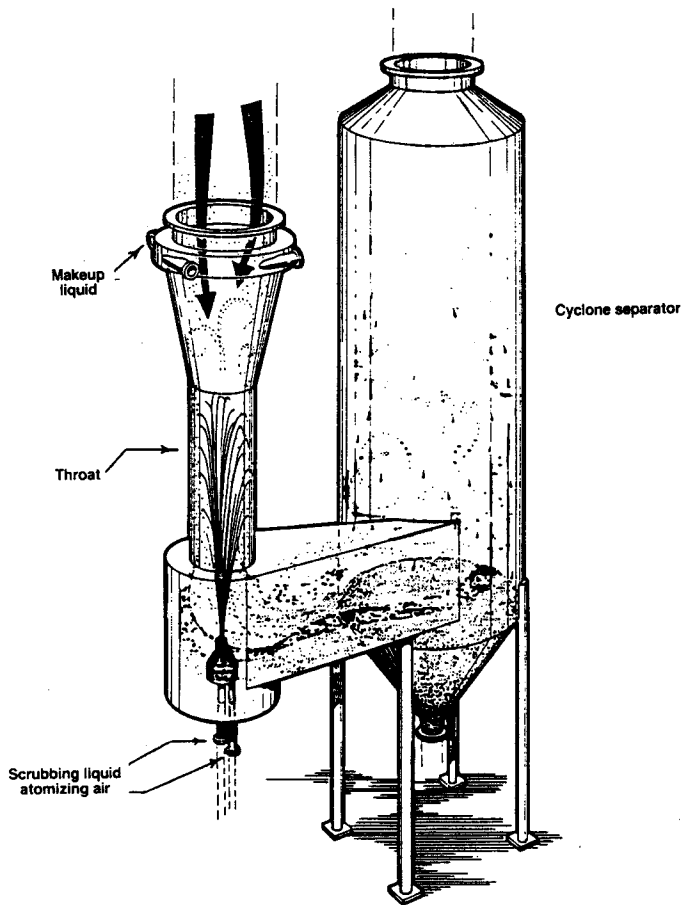


Fig. 8.34. Air atomized venturi scrubber (Courtesy Fuller Co.)

Electrostatic precipitators

Electrostatic precipitators have proven to be good alternatives at mill locations where low pressure drop scrubbers were not adequately collecting the very fine sodium and lime fumes. For this reason, these units have been accepted despite their higher initial capital cost. These units will not reduce sulfur dioxide emissions, however. *Table 8.12* presents a comparison of the advantages and disadvantages of electrostatic precipitators and scrubbers.

Table 8.12. Comparison of 'wet' scrubber with electrostatic precipitator

| | Scrubber | Precipitator |
|-----------------------------|---|-----------------------|
| Capital cost | Lower | Higher |
| Particulate collection | Requires about 5 times hp for same collection | Superior at lower hp |
| TRS/SO ₂ control | Reduction by scrubbing action/lime neutralization | No reduction |
| Stack plume | Noticeable | Not visible |
| Lime dust disposal | To mud washer, which causes mud filtration problems | Directly to kiln feed |
| Space requirement | Less | More |

Figure 8.35 shows a typical electrostatic precipitator configuration. The entire unit is enclosed in a rigid casing which may comprise one or more chambers. In North America, only single chamber units are in use. Multiple chambers are preferred for large gas flows and in applications where a chamber needs to be bypassed for maintenance, such as on recovery boilers. Each chamber can have multiple electric fields, and two or three fields are typical of lime kiln applications.

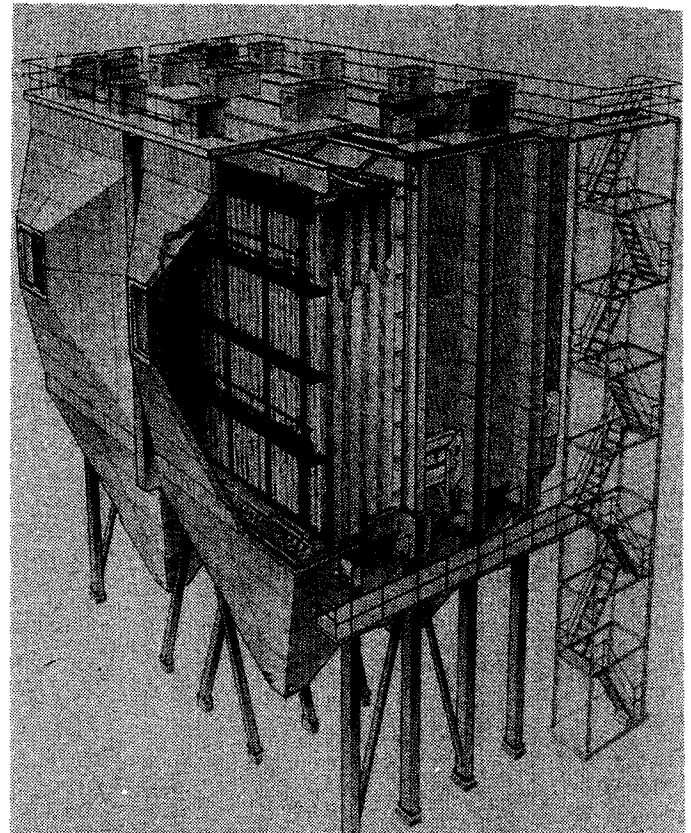


Fig. 8.35. Electrostatic precipitator configuration (Courtesy Airpol)

Inlet and outlet gas flow nozzles have perforated plate distribution screens with an open area that can be adjusted for different flue gas flows. The dust collecting system consists of long collecting plates, mounted off center in groups on support frames. The plates fit loosely into the slots of the rapping bars below. The rapping mechanism is the system's major moving part. Rapping bars transmit energy to the plates when they are rapped by a system of tumbling hammers mounted on a shaft. The bottom hoppers collect the dust removed from the gas and return it to the kiln. Rigid electrodes located between the plates provide a corona discharge.

Precipitator sizing is based on the following variables: gas flow, collection efficiency (i.e., dust loading), gas temperature, gas moisture content, incoming dust concentration, and electric resistivity of the dust. Gas velocity normally is kept below 3 ft/s. The specific collection area (collection area per unit of gas volume) is a useful parameter when comparing precipitator loading.

Cyclone separator

Many lime sludge kilns recently have been installed with cyclone separators directly above the feed end housing ahead of wet scrubbers. The dust collected is directly returned to the kiln. *Figure 8.36* shows a typical arrangement.

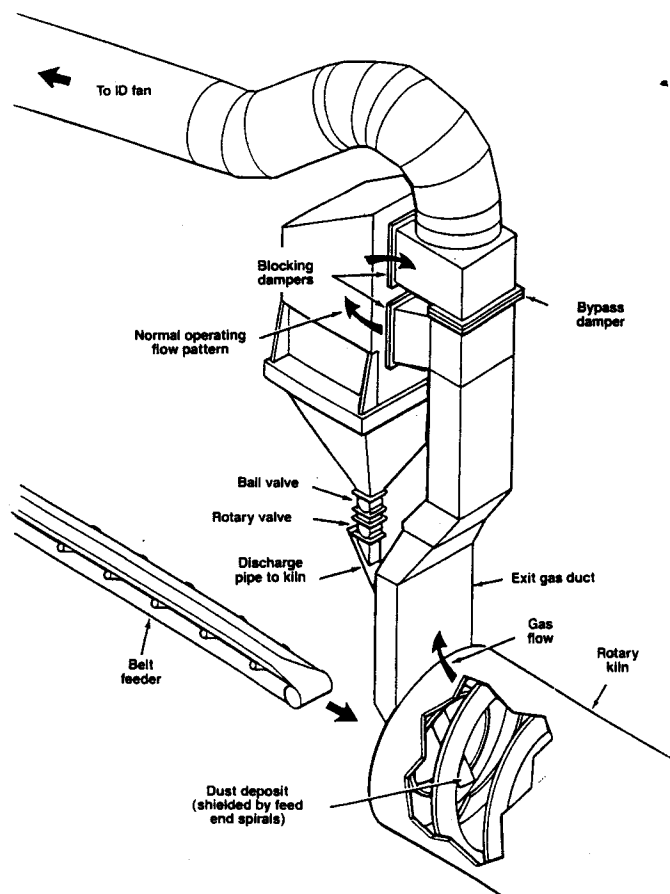


Fig. 8.36. Dust collection system for lime recovery kiln (Courtesy Boliden Allis)

The cyclone separator minimizes the dust load to the wet scrubber and cleans up the kiln exit gas. A separator can be used in an existing kiln to reduce dust emissions by removing bottlenecks in the wet scrubber. The clean gas will have less dust, which will minimize wear on the ID fan. The separator dust is directly returned to the kiln, so fine dust material recycled with the scrubber effluent is reduced with consequent improvement in precoat filter and kiln performance.

A cyclone separator typically has pressure drop of 3 in. of water. Therefore, it is necessary to check the rating of the kiln ID fan before installing a separator.

Flash drying

Flash drying systems offer a means of increasing production rates and reducing fuel consumption. The flash dryer dries the mud outside of the kiln, thereby increasing the volume of the kiln that is devoted to preheating and calcining. The addition of a flash dryer corresponds to an

extension of the kiln shell, but without having to erect a new concrete support pier, adding a kiln shell extension, or relocating the feed end building and exhaust system.

The flash dryer typically would be installed with an existing kiln that requires a substantial production increase and a fuel consumption decrease. A production increase of up to 40% and a fuel use reduction of 10–30% are possible when a dryer is retrofitted to an older kiln.

Early flash dryer designs featured a cage mill in the mud drying section and a cyclone separator to recover the dry mud. More than a dozen of these systems were installed on short kilns, but only two or three are still in operation. Mud at about 60% solids is conditioned by mixing it with dry mud from the cyclone and discharging it into the hot exhaust gas stream from the kiln. The cage mill mixes the hot gases with the mud, which is dried and recovered in the cyclone. The kiln shell acts as a calciner only because the mud comes in hot.

Newer designs have eliminated the cage mill because of maintenance problems. *Figure 8.37* shows a system that accomplishes mud drying to 1% moisture content in a vertical duct where the mud cake from the belt or screw feeder encounters hot kiln gases. The kiln gases entrain the mud and drying is completed rapidly. The dried mud is separated from the hot gases in a cyclone separator and fed to the kiln. Four such systems are in operation in Scandinavia.

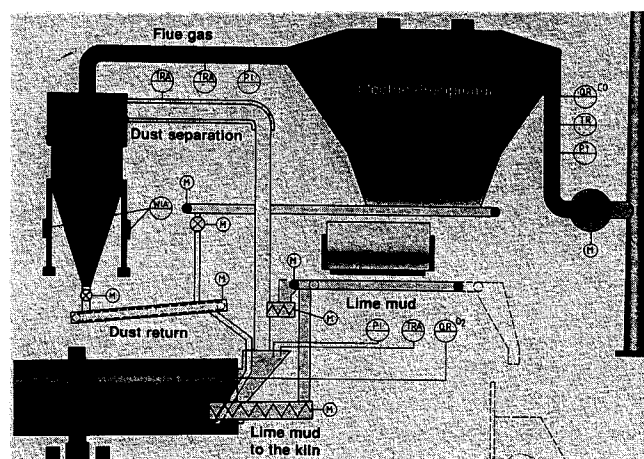


Fig. 8.37. Lime mud flash dryer (Courtesy Ahlstrom Recovery)

Instrumentation

A typical lime instrumentation system is summarized in Table 8.13 and illustrated in Fig. 8.38. Some of the controls are looped or interconnected; these loops can be operated automatically or manually.

Table 8.13. Kiln instrumentation

| Instrumentation | Function |
|---|---|
| 1. Mud slurry density and flow control | Controls mud density to precoat by adding water/filtrate. Flow maintained by control valve. Both loops control kiln operating rate. |
| 2. Exit gas temperature control | Fuel flow is adjusted to keep temperature at preset value (350–500°F range). |
| 3. Primary air fan damper control | Controls primary air flow to burner by adjusting damper position. Minimum primary air flow is best for flame control. |
| 4. Secondary air fan damper control | Controls secondary air flow in kilns without coolers. Maintains kiln draft and exit oxygen level. |
| 5. Fuel oil or gas flow control | Controls fuel rate as a function of kiln exit gas temperature. |
| 6. Exit gas oxygen analyzer | Maintain oxygen at 1–2% level by adjusting the ID fan damper or speed. |
| 7. Exit gas combustibles analyzer | Monitors CO and other combustibles. Operator can adjust air or fuel flow. |
| 8. Firing zone temperature | Recorded with optical pyrometer. Guide to adjust fuel flow. |
| 9. Mid-kiln temperature | Recorded with infrared gas thermometer. |
| 10. Firing hood and feed housing draft gauges | Monitor the small negative pressure in the kiln to prevent dust from puffing out. |
| 11. TRS monitor | Records TRS emission level. |
| 12. Kiln rotation speed | Measures kiln speed. |
| 13. Scrubber differential pressure | Measures pressure drop across venturi. |

Ammeters are provided to measure motor current on key moving parts such as kiln drives, fans, and conveyors to alert operators to possible mechanical malfunction. Flame safety controls are provided to shut off the fuel in the event of fan failure or kiln stoppage. Automatic ignition and controls are provided for the fuel system.

The most important operating variables to be watched for are: lime mud density and flow, kiln exit gas temperature, firing hood draft, burning zone temperature, exit gas oxygen and combustibles content, and scrubber differential pressure.

A rotary kiln system has a long reaction time, and at any given time a large quantity of lime mud and mud is in process within the system. Therefore, the operator has sufficient time to take corrective action when trends or change in the operating variables are detected from the instrument readings. Changes to compensate for variables should be made in small increments, allowing sufficient time to observe the effect after each change. Overreaction leads to overcompensation, which causes cycling and upsets that may take hours to return to normal operation.

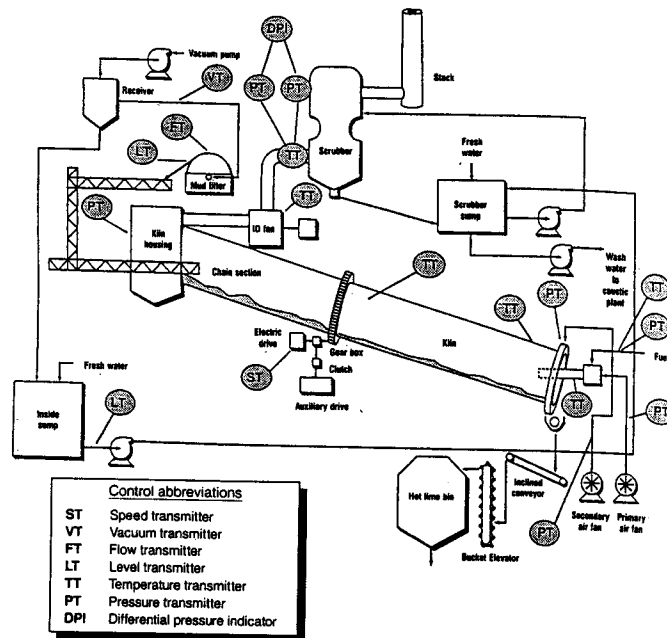


Fig. 8.38. Typical instrumentation applications in a modern kiln

Lime testing

Soft burned lime is highly reactive to H_2O and CO_2 in the air, both of which will lower the available CaO test on the product. All samples should be held in closed, airtight containers until the samples are analyzed by the laboratory. TAPPI Useful Method 616 "Analysis of Kraft Lime Sludge" and TAPPI T 617 "Analysis of Lime" outline the procedure for sampling and testing.

The following samples are recommended for laboratory testing:

- (1) Mud feed to the filter: composite shift samples taken and analyzed for percent solids and percent Na_2O
- (2) Filter cake from filter: composite shift samples taken and analyzed for percent solids, percent Na_2O and percent $CaCO_3$ (dry basis)
- (3) Kiln product: composite shift samples taken and analyzed for available CaO and residual carbonate content.

Some mills check the slaking time of a weighed amount of lime in a measured amount of water. In addition, hourly grab samples of the kiln product should be tested by kiln area personnel for percent calcium carbonate.

Air emission control

The U.S. Environmental Protection Agency (EPA) new source standards for emission limits from lime kilns in the pulp and paper industry set a performance standard of 8 parts per million (ppm) by volume of total reduced sulfur (TRS) expressed as sulfur and corrected to 10% oxygen. In May 1979, the EPA promulgated guidelines for retrofitting emission controls to existing kraft mills and established 20

ppm TRS from existing lime kilns. Most of the states have adopted the 20 ppm as an acceptable limit for TRS from existing lime kilns.

The most critical factor in TRS emissions is the residual sulfides contained in the mud fed to the kiln. Sulfides in the feed are stripped by the CO_2 in the kiln flue gas and discharged as hydrogen sulfide and organic sulfides (TRS). These gases are highly malodorous.

The quantity of residual sulfide in the mud is determined by the efficiency of the lime mud washing and thickening operation. Oversized precoat vacuum filters that are operated with a thin filter cake are required to oxidize the residual sulfides on the filter drum. The kiln itself contributes little, if any, help in oxidizing these reduced sulfur compounds; these compounds must be oxidized and/or removed before they enter the kiln. A wet scrubber dust collector will help reduce TRS in the exhaust gases, but an electrostatic precipitator will do little to reduce TRS emissions.

Some kilns are operated with excessive amounts of oxygen and higher than normal exhaust gas temperatures. Although this helps in oxidizing the TRS, it also increases the kiln's fuel requirements.

Additional governmental regulations have been proposed to limit the amount of SO_2 that can be discharged from the stack. Sulfur dioxide is generated in a kiln that burns No. 6 oil and noncondensable gases. No. 6 oil contains at least 2% sulfur, and SO_2 is formed in the products of combustion when the oil is used to fire a kiln. The noncondensable gases contain a large percentage of reduced sulfur compounds that are oxidized to SO_2 when burned in the kiln. The lime in the kiln will neutralize or react with some of the SO_2 to form calcium sulfate, but not all of the SO_2 will be absorbed. Some of the SO_2 will also be neutralized in a wet scrubber. Stringent sulfur dioxide emissions requirements may necessitate treating the exhaust gases after the dust collector with a caustic soda solution, particularly the gases on the clean side of an electrostatic precipitator.

In order to keep TRS and SO_2 emissions as low as possible, contaminated condensate water from the digester and evaporator must not be used as scrubber recycle water or as shower wash water for the mud filter.

Burning pulp mill noncondensable gas

Noncondensable gases (NCG) containing reduced sulfur compounds from the digester and evaporator plant are often burned in the kiln as a means of controlling odorous emissions from these sources. There are several ways to introduced NCG to the discharge end of the kiln. One method is to introduce the concentrated gases directly into a separate pipe or burner tube in the kiln burner, where they will be immediately incinerated in the burner flame. Some of the collected noncondensable gases are diluted with a large quantity of air. Introduction of these high volume, very diluted gases directly in the kiln burner is not practical, because burner operation will become unstable. In some mills, the large volume of diluted NCG is directed to

the shroud around the tube coolers and mixed with the secondary air that is used for cooling the product in the coolers. A number of mills have stainless steel tubes or pipes in the face of the fire hood or fire shield, and the diluted NCG are introduced to the inside of the fire hood.

Backup flame safety devices are required when burning noncondensables, and the noncondensable gas line should be fitted with flame suppression and venting devices. Controls are required to divert the NCG to a back-up incinerator or to the atmosphere in the event of a kiln outage. Heavy buildup or coating on the refractory has occurred at some mills. This heavy coating normally starts about 10 ft from the discharge end of the kiln and extends 50–70 ft up the kiln. For the most part, this coating is calcium sulfate (CaSO_4) that is formed by the reaction of the lime and the sulfur compounds in the NCG.

Acknowledgements

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3. Fuller-Traylor Pulp and Paper Industry Seminar, Bethlehem, Pa., October 1989.

Note: Boliden Allis has changed their name to Allis Mineral Systems.