The recovery and use of paper for recycling have been on the increase, as the proportion of fiber obtained by recycling has been increasing. Globally, recycled fiber accounts for well over 40% of pulp fiber (**Table 1**), and some countries have achieved much higher rates (over 50% in Japan and around 60% in Germany). Although product needs and capacity growth may constrain the use of recycled fiber in some cases, there is still the potential to expand its recovery and use in the future.

See also: **Papermaking**: Overview; The History of Paper and Papermaking; World Paper Industry Overview. **Pulping**: Environmental Control.

Chip Preparation

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Introduction

Wood chips used in pulp mills are small, engineered pieces of wood cut from logs and wood pieces left over from the manufacture of solidwood products such as lumber and plywood. The target dimensions of a chip are usually 4–6 mm thick, 15–20 mm in length and width (**Figure 1**). This is the size range that will allow most batch and continuous chemical and mechanical pulping systems to reduce the wood uniformly to individual fibers and fiber bundles. There is no 'perfect chip' since wood variability does not allow consistently making the same chip over and over. There is an ideal chip size distribution that matches the needs of the mill's digester(s). This article will describe the process of making chips that meets the specifications of pulp mills. The basic chip production processes are:

Figure 1 Typical pulp chips sampled after going through the chip screen system.

- debarking of logs increases pulp yield and cleanliness
- chipping of logs and wood products residuals makes small particles (called chips) in as uniform size distribution as possible
- chip screening removes fines and oversize chips to improve pulping uniformity
- prevention of contamination of chip flows with metal, rocks and especially, plastic
- chip transportation and storage systems receive, store, convey, and meter chips without damaging them
- quality control programs monitor chip production and deliveries.

Mill Layout

The area in the mill that logs and chips are received, stored and processed is called the woodyard. The building or structure that contains debarking, chipping, and screening equipment is the woodroom. In cold climates, almost all the functions are contained in heated buildings to prevent freezing of equipment and people. In more temperate zones, only a sheltering roof is used to protect the chipper and screen from rain.

The goals of the woodyard and woodroom organizations are to:

- produce chips that are not only the right size for the mill's digesters, but also have very low short-term variability (i.e., hourly and daily)
- deliver chips to the pulp mill that have little or no contamination and a bark content that is below the mill's tolerance level
- manage the inventory of logs and chips at target levels that do not create a loss in chip value from deterioration in storage
- monitor the quality of chips received at the mill, made in the wood room and delivered to the digester with sampling and testing frequency consistent with the use of the data for decision-making.

Debarking

Bark is essential for a tree's growth and health. It is a protective layer around the wood that resists drying, attack by molds, wood staining and rotting fungi,

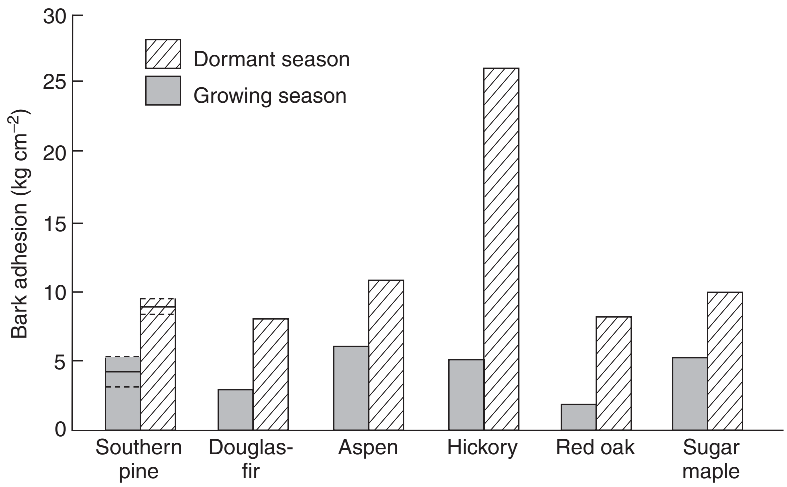

Figure 2 Comparison of bark adhesion for several common North American pulpwoods showing the difference between the tensile force required to remove the bark in dormant and growing seasons.

and most insects. Between the wood and the bark there is a single growth layer called cambium. This single cell layer is where tree growth occurs. Bark is formed toward the outside of the tree and wood to the inside. During the growing season, this layer breaks easily and bark is removed with little force. However, during the dormant, winter season, the bark and the wood are tightly bonded together by the inactive cambium layer and more force is needed.

The mechanism of bark removal is applying enough force to break the bond between the bark and the wood. The amount of force has been quantified for the most common North American wood species for both dormant and growing season conditions. **Figure 2** shows that bark adhesion approximately doubles in the winter for most wood species. In the industry, it is well known that debarking hickory (*Carya* spp.) is almost impossible in the winter and the data shows its high bark adhesion. At the other extreme, the bark of some hardwoods, like poplar (*Populus* spp.), is so loosely attached in the spring that it easily falls off in big sheets that are difficult to convey and process into wood waste fuel.

Other factors also influence the ability to remove bark. Thick bark absorbs energy and requires more time or force to remove it. Logs dry out after long storage times and the bark bonds to the wood more tightly.

There are two primary types of equipment to apply the force needed to remove bark from logs. In sawmills and plywood plants, mechanical ring debarkers are most common. **Figure 3** shows how debarking tools surround and rotate around each log. The tools are sharp and press against the log. The bark is peeled off the log and drops down to a refuse conveyor going to the wood waste fuel or bark products processing systems. While the linear speeds of the debarkers now reach 150 or more meters min^{-1}, this type of debarker can economically prepare logs for sawing or peeling.

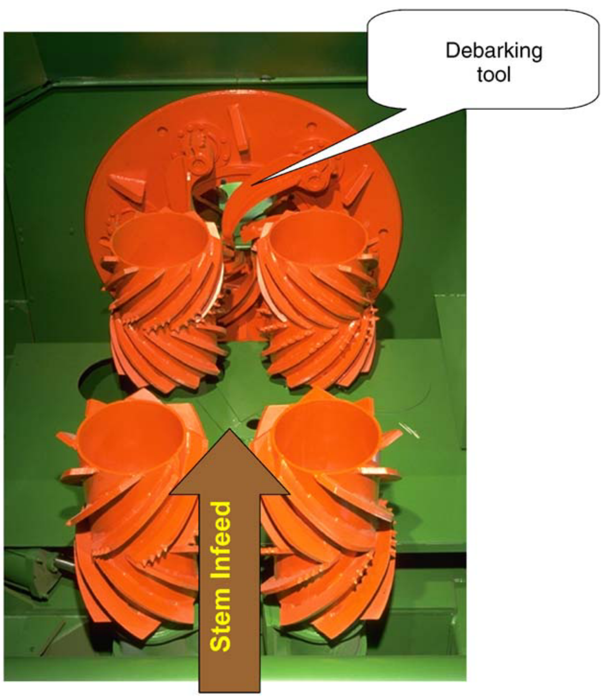

Figure 3 Mechanical 'ring' debarker. The debarking tool pressure on the log surface is adjusted for the diameter, storage time, and season.

In pulp mill woodyards, large drum debarkers ranging from 4 to 8 m in diameter and over 60 m long can debark up to 100 to 250 cm^3 of logs h^{-1} (**Figure 4**). Wood comes to pulp mills in two forms, shortwood and longwood. Shortwood tumbles

Figure 4 Long-log drum debarkers in an area with cold climate where equipment must be enclosed for winter operation.

randomly and longwood rolls in parallel against each other as the drum turns. The drums rotate at 6–10 rev min^{-1}, adjustable in more modern installations. Logs are fed into the open infeed end of the drum and the level is optimally about 50% full. Since the drum outlet is about 1 to 2 degrees lower than the infeed, the logs move down the drum. An adjustable vertical, horizontal, or elliptical discharge gate controls the rate of debarking. Operators control the residence time in the drum by adjusting the feed rate and the gate position. The tightness of the bark determines how long the wood must stay in the drum to keep the bark levels below the mill's tolerance levels. During the spring and early summer, it typically takes half an hour or less to reduce bark levels to well below 1%, depending on log size and species. In autumn and winter, the residence time may need to be as long as 1 hour to achieve the same low bark levels. However, long residence times will cause excessive wood loss as the logs hit each other and the walls of the drum. A balance must be achieved so that wood loss is controlled and bark levels are near the tolerance limit. The bark tolerance level varies between mills depending on the wood species, bleach sequences used, and customer demands for clean pulp and paper. In a survey of North American mills, a bark tolerance level in the range of 0.5–2% was typical. High debarking efficiency with low wood loss will achieve one of the primary objectives of the woodyard in reducing the bark content below the tolerance limit of the mill.

Chipping

Pulp mill chips are produced either in a pulp mill woodroom at a wood products mill, and most commonly, at both. The basic chipping mechanism is the same for each, but the difference in the wood sizes and shapes requires different sizes and types of chipper systems. Sawmill waste chipping is more challenging since the infeed material varies widely in size and shape (**Figure 5**). In general, woodroom chippers will be larger in diameter (1.8–3.1 m) than sawmill chippers (1.2–1.8 m). The life expectancy of a woodroom chipper is 30 years or more, while sawmill chippers are lighter duty construction and have a 10–15-year life.

Figure 5 Sawmill chipper infeed. Vibratory conveyors are commonly used to convey sawmill waste to chippers. The size and shape of sawmill by-products varies widely. Some flows are relatively uniform (a) while others contain long slabs, trim blocks, and chip screen oversize (b). uniform sawmill chipper feed material produces more uniform chips.

The basic chipping mechanism is a sharp knife passing through the wood, cutting across the grain (**Figure 6**). There is first a cutting action and as the knife continues to move into the wood a shearing action that pops off chips. This continues until the knife has cut completely through the log or piece of wood when the next knife begins its cut. Chippers have multiple knives mounted on a disk or a drum. The disk chipper is the most common (**Figure 7**). A slot is cut radially through the disk so that the chips will exit from the back of the disk after being cut. The knives are mounted at each of these slots with a clamp mounting or a face mounting (**Figure 8**).

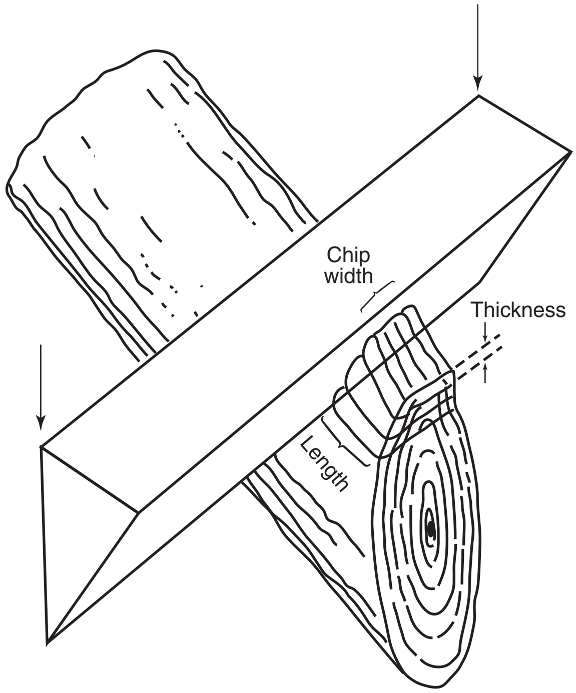

Figure 6 Chip cutting action. Only the chipper knife and log are shown in this drawing of how chips are formed as the knife passes through a log. The knife cuts the wood off at the desired length. As the knife continues into the log, it creates shear forces that pop off a chip at the designed thickness. As chip length increases, chip thickness also increases.

A woodroom chipper infeed system has these basic parts: (1) an infeed conveyor moves the logs from debarking to the chipper; it is usually a heavy link chain, heavy-duty rubber belt conveyors or a combination of the two; (2) the infeed chute guides the wood from the conveyor to (3) the chipper spout at the disk face. The chute is commonly at a 38-degree angle to the disk. The chute can be oriented to feed the wood by gravity or pulled in horizontally by the knives (**Figure 9**).

A disk chipper has 4–12 clamp-mounted knives positioned radially along slots that pass through the chipper disk. The chips will go through the disk after the knife cuts them off the log. Mounted on the back of the chipper disk are fanlike blades that catch the chips and blow them out of the top of the chipper hood. Without these blades, the chips fall onto a conveyor below the chipper. This is a bottom discharge compared to the overhead or blown discharge. The blades often have protrusions that break up the ribbon or card of chips that pass through the disk.

The layout of sawmill residual chippers is quite similar to a woodroom except that the material chipped is much smaller and has a wide variety of sizes (**Figure 5**). Sawmill chipper infeeds can be at either a right angle to the chipper shaft or as in some newer sawmill systems, the disk is tilted over the infeed chute, exerting more pull-in and hold-down forces on sawmill residuals or small logs.

Chipper maintenance is critical in producing an optimum chip size distribution. Maintaining the designed wood to knife interface requires daily, weekly, monthly, and yearly inspections and replacement of parts when the wear limits are exceeded. Most wear points can be checked during knife changes. Chipper knives can wear quickly depending on the tonnage being chipped, the wood species, the moisture content of the wood, and the amount of rock and metal contaminants that reach the chipper. Simple wear only requires grinding, but grinding done carefully so that correct knife angles are restored and metallurgy not altered by overheating. Other key wear areas are the anvils, bed knives, and face plates. Deciding the timing for knife changes depends on the rate of wear, the chip quality needs, and the times the mill making chips or the woodroom is down for enough time to change knives and inspect the chipper without losing production time. Shift changes and meal breaks are such times. The best way to decide when knife changes are needed is by tracking the chip quality. There is a gradual increase in pin chips and fines after a knife change. Depending on the mill tolerance for small particles and screen capacity, a tonnage or time for knife changes is decided based on chip quality and normal downtime schedules.

A 'disposable chipper knife' has become popular in the last 10 years. These knives have two chipping edges, are in segments about 40–60 cm long and are turned around and relocated on the disk in a pattern that takes advantage of the fact that some zones get more chipping action than others. **Figure 10** shows a cross-section of a disposable knife, knife holder and method of mounting the knife.

Chip Screening and Cleaning

Each pulping system operates best with a specific chip size distribution. Finding that distribution is

Figure 7 (a) Horizontal feed disk chipper and approx. 50 cm diameter fiber log; (b) gravity feed disk chipper and 15–20 cm diameter shortwood; (c) horizontal feed disk chipper and approximately 30 cm diameter fiber logs; (d) drive side view of a horizontal feed disk chipper; note the straight line design from the drum to the feed that eliminates log transfers and plug-ups; (e) chipper operator changing chipper knives; required safety equipment is being worn and a holding device has been made to reduce the risk of cuts while handling the newly sharpened knife; (f) the back side of a chipper with card breakers during a knife change; note that the chipper slots have been lined with a wear plate to prevent disk damage over time.


(a)
(b)
(c)
(d)
(e)
(f)

Figure 8 Woodroom chipper with hood raised for knife changing. The knife slots and knives reach from the hub to the edge of the chipper.

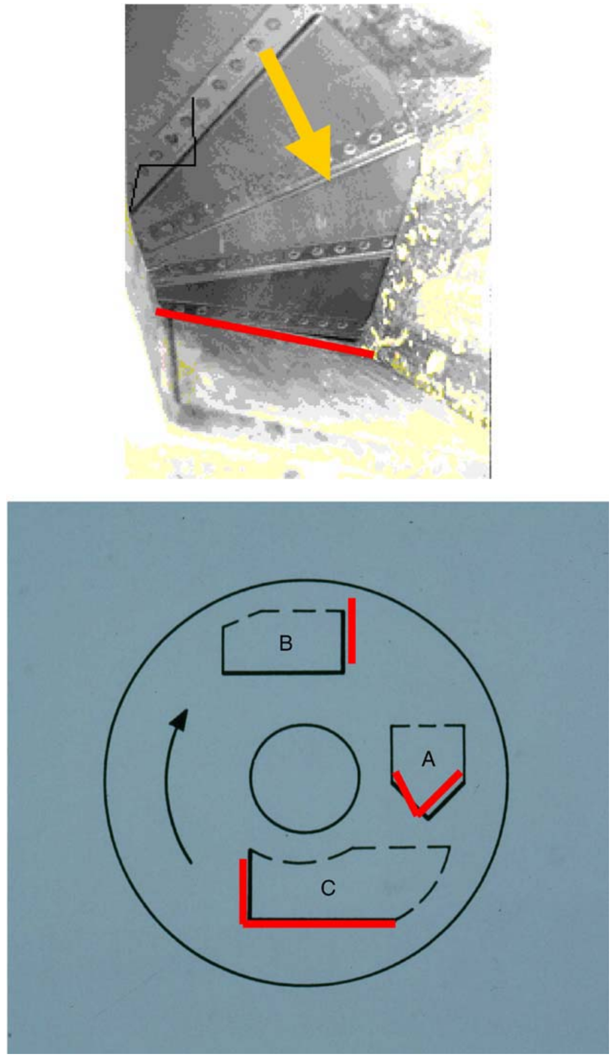

Figure 9 Spout location is a key part of chipper design. The picture shows a chipper spout with the direction of rotation marked with an arrow. The anvil location is marked with a red line. This design keeps wood in the lower right corner for uniform chipping. The sketch shows typical anvil locations of other designs: (A) a gravity feed with anvils at both of the bottom edges, (B) a horizontal spout overshaft with a vertical anvil, and (C) a spout undershaft horizontal feed with bottom and side anvils. Design (B) is not recommended for roundwood applications since the wood is lifted up against the force of gravity and wood (logs or sawmill residuals) do not remain stable.

done with well-planned mill trials, pilot scale trials at a screen manufacturer's facility, applying information reported at a conference, literature searches or simply by observing how the day-to-day operations fluctuate as chip quality changes. These are listed in the order of likely success. Given an optimum size distribution, a chip screening system can be designed that meets the mill's needs. The size fractions most commonly removed from a chip flow are over length, over thick, pin chips, and fines (as defined by a Chipclass classifier in **Figure 11**). A well-designed screen system will remove a target size at high efficiency with low loss of good fiber.

The goal of a pulping system is to make pulp at the highest yield possible, with low variability the pulp properties that meet the customer needs. One of the most important contributions a woodroom can make to pulp mill operations is narrowing the chip size distribution after everything has been done to make optimum chips in the woodroom, sawmills, satellite chip mills, and plywood plants. Pulp chip screening equipment is designed specifically to remove and often reprocess the extremely large and small chip sizes.

There are several classes of chip screening equipment:

1. Rotary or gyratory screens. Although the first type of chip screens to be used in woodrooms, these screens are still used alone in sawmills or in combination with some of the more recent screening concepts in woodrooms (**Figure 12**). This type of screen segregates chips on the basis of length or width using flat punched steel plate or woven wire mesh stacked up to three or more decks. The circular or elliptical motion of the screen is in the horizontal plane of the plates. The top deck has the largest square, circular, oval, or rectangular openings 40–60 mm in diameter, length, or diagonally. Oversize chips are rechipped in a small drum or disc chipper. To remove the smaller fractions, plates or steel mesh with 4–6 mm round or square openings are placed in the bottom deck of the screen. The screening efficiency of this type of screen is relatively low. Typically, the small fraction removal efficiency is

Figure 10 A cut-away section of a disposable chipper knife clamped into a knife holder that is then bolted into the knife pocket. Note the two chipping surfaces that allow the knife to be turned over when one side becomes dull.

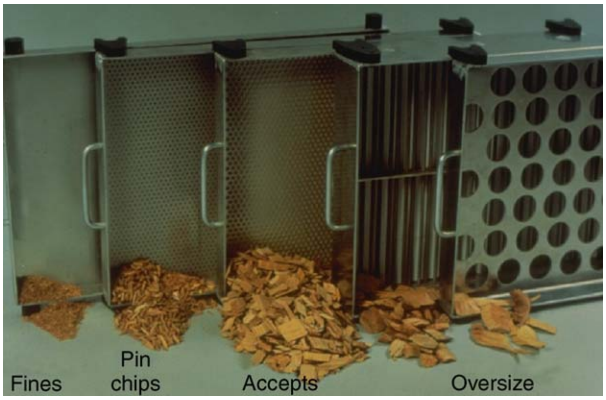

Figure 11 Chip classifier tray series that relates to pulping and chip handling operations. Oversize undercook, causing high dirt levels due to uncooked wood in the center. Feeders and chip chutes can plug due to long oversize. Pin chips can impede digester liquor circulation in high or highly variable amounts. Fines contain fibers that are too small to make good paper and contain high amounts of dirt and bark contaminants.

no more than 50–65%. A rotary/gyratory screen is usually a component of a multiscreen woodroom screen house and due to its simplicity, is used in sawmill and veneer plants.

Figure 12 A typical gyratory screen. Note that the round holes are larger in the feed end of the screen and smaller at the discharge end. This has been used to increase screen capacity, but actually reduces removal efficiency.

2. Disk screens. In the 1970s the industry became increasingly aware that chip thickness was as or more important than chip length. The disk screen is designed to remove over thick chips. A series of parallel shafts at a 90 degree angle to the chip flow have thin disks spaced uniformly and rotate in the same direction. The disks alternate and overlap so that the interface opening between opposing disks is in the range of 6 to 10 mm (**Figure 13**). Unscreened chips are evenly fed across the first rows of disks and the rotating motion moves a mat of chips down the screen with the help of undulations or serrations on the disk edges. The thinner, acceptable chips and small particles fall between the disks while the over thick and over length ones drop off the end of the screen. High screening efficiency always translates to some near-size acceptable chips staying with the rejects. During the process of treating the rejected oversize and carry-over of unacceptable chips, some of the fiber loss will be recovered. Disk wear is a significant issue for disk screens. Periodically, the interface openings should be checked with calipers and chip samples taken to determine the overall system efficiency. In areas where sand contaminants are found, the interface opening is increased in as little as 18–24 months. Some early attempts to screen out small particles with disk screens were commercially unsuccessful due to plugging, sensitivity to chip moisture content, and wear.
3. Roll screens. The development of roll screens to segregate both large and small particles has provided greater flexibility in screen system design and operation. The rolls are arranged with their shaft at a right angle to the chip flow. The roll surface is machined to form a pattern of diamond

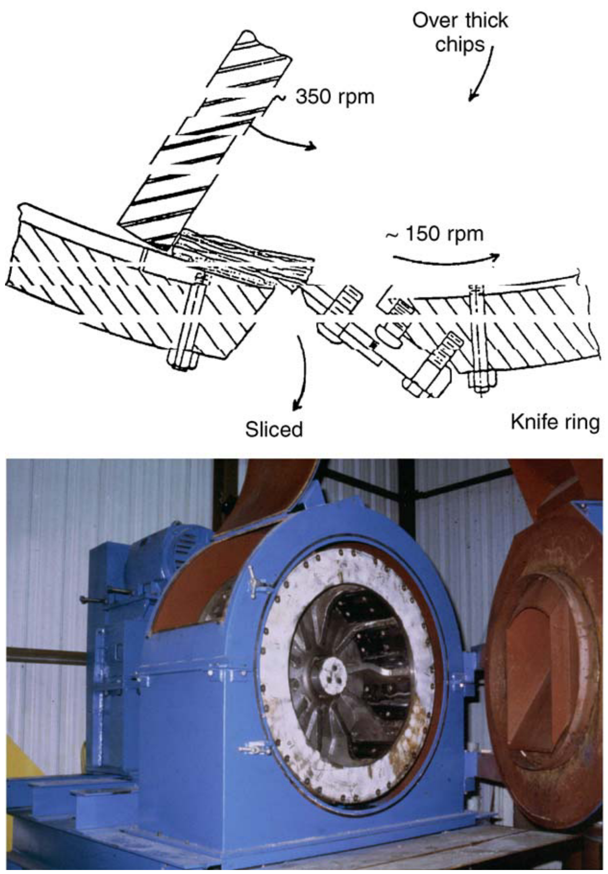

Figure 13 Chip slicing. The two rings in the slicer rotate in the same direction, but the inside ring brings the chips to the knife at a faster speed than the knife ring is rotating.

shaped peaks and valleys (**Figure 14**). The inter-roll opening is adjustable from 1.5 to 8 mm. Thickness screening is possible using the inter-roll opening to reject over thick and over length chips. The application of roll screens to fines screening and pin chip recovery provides the ability to tune the system by adjusting both the roll speed and the spacing. This is particularly important in responding to the higher pin chip and fines content produced by chippers in the winter months. Over time, the mix of sawmill chip supplying a mill will change and with it the average size distribution. The adjustability of roll screens provides the unique opportunity to respond to change without the high cost of system rebuild.

4. Bar and blade screens. Another way to provide an interface opening through which oversize chips cannot pass is the arrangement of segments of bars or thin blades that oscillate the length of the screen to move the chips down the screen and separate the over length and over thick chips. Wear is much slower in the bar screen than any other.

Over length, over thick, and accept chips rejected by thickness screens need treatment before they can be put back into the chip stream. The composition of the over length and over thick chips is dominated by wood knots and the distorted wood around branches. A few wood and pulping experts contend that the wood in these oversize categories is very high in compression wood and therefore should be diverted into the mill fuel system. Very few mills have analyzed this option and most mills continue to reprocess the oversize material to make it pulpable. The options available for rechipping and oversize treatment include:

1. Rechippers. Both disk and drum versions of rechippers are available. Disk rechippers are 1–1.5 m in diameter. Both horizontal and gravity feed are common. Tests have shown that it may take as many as three to five passes before a rechipper will reduce some oversize pieces to a size that will be accepted in rescreening. Fines production is increased by rechipping from random cutting and repeated recycling. The inadequacies of a rechipper has encouraged the development of better options, particularly since thickness screening implementation began in the 1970s.
2. Chip slicer. A machine that normally makes flakes for the production of flakeboard has been adapted to slice over length and over thick chips to a thickness that will pulp more easily (**Figure 13**). Oversize and carried-over accept chips are fed into the center of a drum surrounded by two concentric rings. Slicer knives are mounted on the inside of the outer (knife) ring that turns at about 150 rpm and in the same direction as the inner or anvil ring. At about 350 rpm, the inner ring anvils sweep the oversize material into the slower moving knives. A slice is taken at the target chip thickness (6–8 mm). As long as a rock or metal contaminant does not damage the knives, slicers have operated for 6 to 8 weeks before a knife change was needed. Four weeks is about average.
3. Chip crackers or conditioners. The poor pulpability of oversize material is due to the inability of pulping liquor to penetrate the chip. In laboratory studies, it has been observed that large chips that have partially separated during chipping will pulp almost as well as accept chips. It follows that if fissures can be created in oversize chips, liquor penetration should be sufficient to achieve pulping. This has been commercialized in chip crushers or conditioners (**Figure 14**). The oversize chips drop through the nip between two large rolls turning toward each other. There is pressure applied to prevent the nip from opening

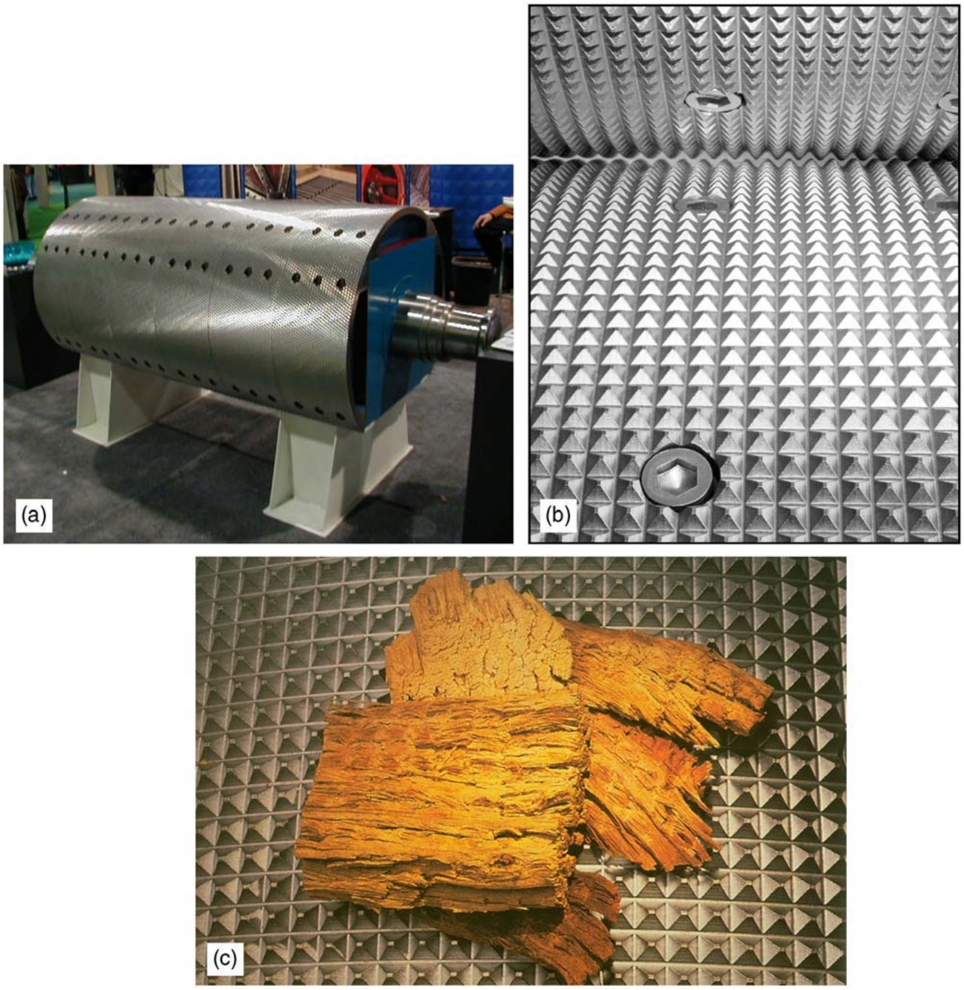

Figure 14 Chip cracker or chip conditioner. (a) One of the pair of rolls in the system; (b) close-up of the inter-roll opening; (c) examples of oversize after going through the roll opening. Note how the large chips are fissured by the crushing force and the roll surface.

when several chips go through at the same time. There is less maintenance since there are no knives to sharpen. The roll surface metallurgy resists abrasion and the occasional wrench. As with chippers and slicers, there needs to be protection from the occasional tramp metal and rocks that find their way into chip supplies.

Wear and equipment damage is a major problem in rechipping, slicing, and crushing oversize chips. Rocks and metal debris are particularly troublesome. Since both of these materials sink in water, running the oversize through a chip washer or settling basin will eliminate this problem. Sand and grit can be removed in a chip washer in much the same way as rocks. Mechanical pulping systems almost always have chip washers to reduce wear in the primary refiners.

In regions where freezing conditions preclude the use of water as a separation medium, air density separators have been highly successful. The oversize chips are fed into a vertical pipe that contains upward flowing air from a blower system. By adjusting the air flow, denser rock and metal debris will fall out of the oversize chip flow onto a conveyor belt below while the less dense wood will rise and be caught in a cyclone feeding a slicer, chip conditioner, or cracker.

There are other types of contaminants that must be controlled in the mill area to prevent paper downgrade due to spots and holes in the pulp sheet. Grease, oil, char, paint, rubber, and plastic are some of the most common contaminants. The most difficult of these is plastic contamination. Once plastic is in the pulp, there are very few methods of removing it economically. Plastic is introduced into chip flows primarily by people who do not understand the consequences of disposing of things like a sandwich bag, ear plugs, a candy wrapper, and other debris into a chip truck or onto a conveyor. After

Figure 15 Common plastic items shown before and after kraft pulping. The wrapper on the far left is made of paper and will become part of the fiber furnish. The plastic bag at the far right has become a brittle lattice that will break easily in pulp handling and contaminate several hundred tons of pulp.

spare parts have been installed, the plastic packaging is often left to blow onto chip piles. It is commonly dropped onto the conveyor that is near something being repaired. **Figure 15** shows the results of a laboratory pulping study to determine how plastic reacts in pulping. Plastic will not dissolve in the kraft pulping process. Rather, the heat causes it to shrink, become filamentous, or form a hard tacky glob. The most reliable method of controlling plastic contamination is education of everyone from the point of chip production to the digester. The education must be continuous and effective.

Several types of screen combinations are available to design a screen room system. Sawmills and plywood plants install systems that are simple to operate and have relatively low capital cost. **Figure 16** shows this type of system and the more complex systems used in pulp mill woodrooms. Pulp mills can justify more complex systems based on the improvements a narrower size distribution and reduced oversize and fines can bring to mill operations. For example, the oversize chips in **Figure 17** have been pulped with no slicing or crushing treatment. Kraft pulping liquor could not penetrate more than 2 mm into the over thick chip. The distorted grain of surrounding a wood knot also shows a lack of penetration. One of the first observations a pulp mill makes after a screen room start-up is the dramatic drop in these partially pulped chips and fewer shives, small undercooked slivers of wood that break off of partially cooked chips.

Chip Storage and Handling

Chip storage would not be needed if on-site chipping and chip deliveries from off-site chip sources were precisely timed with the digester(s) demand for chips. A few mills are able to achieve as little as 3 days of inventory. This is the exception. If a mill buys chips from several sawmills, their delivery rate varies widely due to such things as shift scheduling, market conditions, equipment breakdowns, and availability of trucks. Chip mill production varies primarily with availability of logs, weather, soil conditions, and log availability. The amount of chips a mill stores depends on the level of risk the chip buyer and the pulp mill manager are willing to share. If a mill manager wants to have no risk of running out of chips, the chip buyer will maintain a large inventory taking into account the reliability of chip suppliers to fulfill the contracted deliveries. An impending wood products market decline would cause the chip buyer to increase inventory just in case the market slump lasted longer than expected. If the decline does not happen or is shorter than expected, the mill has an even larger inventory. It would seem logical to curtail deliveries, but sawmills and chip mills have no or limited chip storage capacity. This is an expensive approach to inventory management. The money invested in chips could be earning a return in other investments; the high inventory will deteriorate faster than normal and the properties of the chips going to the digester will be more variable. A better strategy is

Figure 16 The sawmill or satellite woodyard screen system (a) with only a gyratory screen is much less complex than a thickness screening system installed in most woodyards (b). Note the aerodynamic separator up-draft tubes can be seen on the closest side of the system.

Figure 17 Oversize chips after kraft pulping. (1) Overthick chip with partial impregnation and a woody center; (2) overlength and over thick chip with only the first few millimeters on the outside that are pulped; (3) the distorted grain and compression wood near a branch created an oversize that has only surface pulping; (4) an over thick chip with a woody center; (5) knotwood creates a badly formed chip that only pulps on the surface.

Figure 18 State-of-the-art chip storage systems. Automated outstocking and reclaim is used to maintain a first-in/first-out pile rotation. The arrangement is either circular (a) or linear (b).

to agree on a level of inventory that the pile should never go below (called a critical level). An estimate of the reliability of sources to deliver is made. Also, how quickly inventory could be replaced if a large supplier(s) could not deliver at all (after a fire, for example). This would establish a target chip inventory and a lower inventory level that if reached would trigger purchase options to be sure the inventory stayed above the critical level. A mill that routinely stored about 175 000 tonnes could comfortably operate at an inventory around 45 000 tonnes. **Figure 18** shows modern circular and linear chip storage systems.

Excessive inventory, long storage times, and physical damage when moving chips around result in two types of losses: physical loss and biochemical loss.

The physical deterioration is primarily fines generation. This occurs in blowlines as the chips impact the walls of the blowline at repeated bends and sharp corners. Fines are also created when chip dozers move chips from unloading systems onto the pile and later, back to the reclaim pit (**Figure 19**). Because chip dozers are so heavy, breakage extends down into the pile half a meter or so. In all cases, acceptable chips break into pin chips and fines. Several studies have measured pin chips and fines generation in full-scale, commercial piles. **Table 1** reports data for a blow line test only. An adequate rule of thumb is that a doubling of fines and a 50% increase in pin chips can be attributed to the combination of tractor activity and pneumatic handling.

Biochemical deterioration is caused by a series of biological events that can heat the pile to a temperature that begins destructive chemical reactions.

Figure 19 Sources of fines generation. (a) Blowlines allow chips to be conveyed around existing equipment but the number and severe angles will break chips up; (b) wear plate or flat-backs should be replaced when worn rather than mended; (c) rubber-tired chip dozers cause less damage per pass than tracked dozers (d). However, high traffic in an area will degrade chip sizes for either type.

Table 1 Southern pine roundwood and residual chips transported through a 250-m blowline with six turns (sum of angles = 280 degrees)

Sample point	*Chip size classes*				
	+45 mm rh over length (%)	*+8 mm bar over thick (%)*	*+7 mm rh accepts (%)*	*+3 mm rh pin chips (%)*	*Passes 3 mm rh fines (%)*
Into the blowline	0.2	2.2	81.6	14.5	1.5
Out of the blowline	None	1.0	73.6	21.8	3.6

rh, round hole (the shape of the classifier tray openings).

Hardwoods deteriorate at least twice as fast as softwoods. This text refers to softwood chips only. Internal pile temperatures are hard to measure without laying wires in the pile as it is built. This is not feasible in normal mill operations, but useful in smaller-scale study piles. A dial thermometer with an extended stem (up to 75 cm) will allow grids of surface temperature to be established and monitored periodically. More simply, an experienced dozer operator knows when areas are heating up faster than normal and can take temperature readings. From studies, the internal temperature is 15–20°C hotter than the surface readings. Following the heating curves in **Figure 20**, the initial heating to about 40–50°C in the first 2 weeks is caused by the growth of bacteria, mold, and the respiration of living sapwood cells in the fresh chips. Further heating is determined by the pile height and the degree of compaction. If the pile height remains at about 15 m and tractor activity is kept to a minimum, the pile temperatures remain at or below 50°C. At 50°C, few molds, wood staining, and wood rotting fungi can survive. However, at this temperature, the acetyl group on cellulose molecules is cleaved off, freeing acetic and formic acid and heat. If the heat cannot escape because the pile is being compacted by dozer activity or more chips being added to the pile, pile temperature will move higher. The higher temperature and acid conditions make the acid forming reactions go faster. If the pile height is increased to 45–50 m and compaction increases with more spreading of new chips on the pile, the temperatures will reach 60–70°C. Further height and consequent compaction increases will bring the temperature to 70–80°C. As cellulose and lignin begin to acid hydrolyze, an autoxidation cycle is begun. At this point, further heating will be determined by the amount of compaction. If heat cannot escape due to the combined actions of tractor activity and increased pile height, the pile will be out of control. There is a high risk that an internal fire will be ignited as temperatures rise above 80°C.

Chips that have been degraded in pile storage by heat have lower pulp yield and strength. The degree of loss depends on the length of time the chips were exposed to temperatures over 65°C. Since mills rarely, if ever, track temperatures in enough detail to develop a time–temperature relationship, the results of samples taken as a degraded pile was dismantled might be useful. The first pulp property that falls off is tear: 10% loss of tear is common in piles stored for 4–6 months at 65–70°C. In those same conditions, burst and breaking length losses will be 1–3%. Pulp yield loss is from 1 to 5 percentage points (e.g., going from 54% to 49%). Badly deteriorated chips with a pH below 3 and a buffering capacity over 100 ml g^{-1} produce pulps at a 30–35% yield and with at least 50% strength loss.

Chip pile measurements Attempting to get the book and physical chip inventory values to agree is very difficult, if not impossible. The values that go into the equation vary quite a lot:

$$\text{Book inventory} = \text{physical inventory} + \text{physical losses} + \text{biochemical losses}$$

Below are the ranges of error in data that go into the equation from a number of studies and mill practice:

- Belt scale weights: 0.5–1% (with good design and maintenance)
- Truck scale weights: 1–2% (in the USA, there is a requirement for calibration and periodic, unannounced, spot checks to confirm accuracy)
- Surveyed pile volume (ground or aerial): 1–3%
- Bulk density (kg of wood per cubic meter of pile volume): as high as 25%
- Moisture content (sample and dry): 2–7%
- Moisture content (meter): 1–2%
- Losses (mechanical and biochemical): 25–50%.

Only a few of the measurements have low error ranges. The best numbers are the green weights from truck scales, moisture content, and the pile volumes from aerial or ground surveys. The errors are cumulative and usually result in unreliable estimates. Using these data results in periodic corrections when a pile is completely reclaimed. The adjustments can be positive or negative.

Better estimates of inventory can be obtained by investing in belt scales before and after chip pile storage.

Chip Quality Control

An important principle in establishing a quality control program is that if the data are not going to be used to make meaningful decisions, there is no reason to do the test at all. A corollary to this is: a testing program will produce meaningless data if samples are taken at the wrong location using incorrect methods.

Sampling tools need to be more than just a shovel gathering a bucket of chips anywhere you can easily get to the flow. The scoop should be large enough to allow oversize chips to be caught. The size of the sample should be only enough chips to do the testing required. This avoids the need to split the sample, a

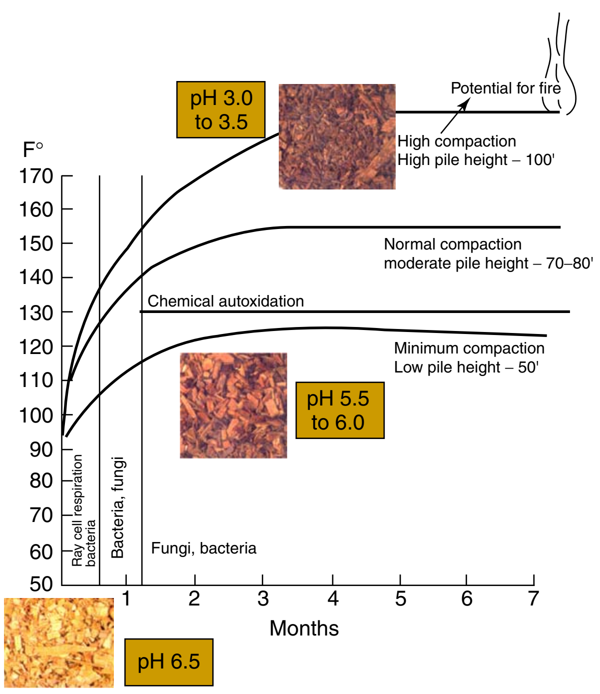

Figure 20 Conifer chip pile temperature profile. The rate of heating and the maximum temperature are primarily determined by pile height and compaction after the first 1–2 months. Initial heating is the result of rapid bacteria growth and respiration of the remaining living cells in the wood. Note the change in pH and color as the chips degrade from exposure to high temperature. The chips in the top photo easily break up into small particles.

process that introduces as much or more error as incorrect sampling. If special testing will require more than the normal scoop full, it is better to collect two scoop fulls and composite them for testing. If a barrel of chips is needed to send to a research laboratory, it should be gathered over a full day to avoid the risk of getting chips from one supplier or type of chip that is only a part of the total chip consumption.

After deciding what chip flows need to be sampled, sampling points must be located where they are safe to access, easy to get to, and allow a sample scoop to be inserted and so that chips can be gathered that represent the entire cross-section of the flow. Belt conveyor transfer points are an ideal place to do this. In most cases, there is access to the entire flow as it falls from one conveyor to the next. If not, a door can be cut in the hood. Access is preferable with the flow of chip coming toward the sampling point. The scoop is inserted upside-down, pushed all the way through the flow, turned over and quickly drawn out to take the sample from the entire depth of chip flow. A permanently mounted tube sampler replicates this sampling process. **Figure 21** shows several standard and tube sampling applications. There are other types of samplers that allow representative sampling of truck deliveries. Since installing samplers is almost always an add-on to existing systems, there are few that are alike. There are commercial samplers available that can be adapted to many situations.

A sample taken from the top of a moving belt or the top of a delivery truck or rail car will always contain fewer fines than a representative sample. As soon as chips are moved along a belt, in a rail car or truck bed, fines immediately begin to percolate downward. Similarly, a sample removed from the lower part of a rail car or chip trailer will be biased with more fines that have moved down the chip bed. Sometimes, a sample taken correctly at a transfer point is not representative. The likely cause is several types of chip flows joining together and one of them being loaded toward one side of the conveyor. The addition of cracked or conditioned oversize back into the accept flow often comes down a chute, depositing to one side of the belt.

The most widely used test methods to track woodroom and supplier quality performance are:

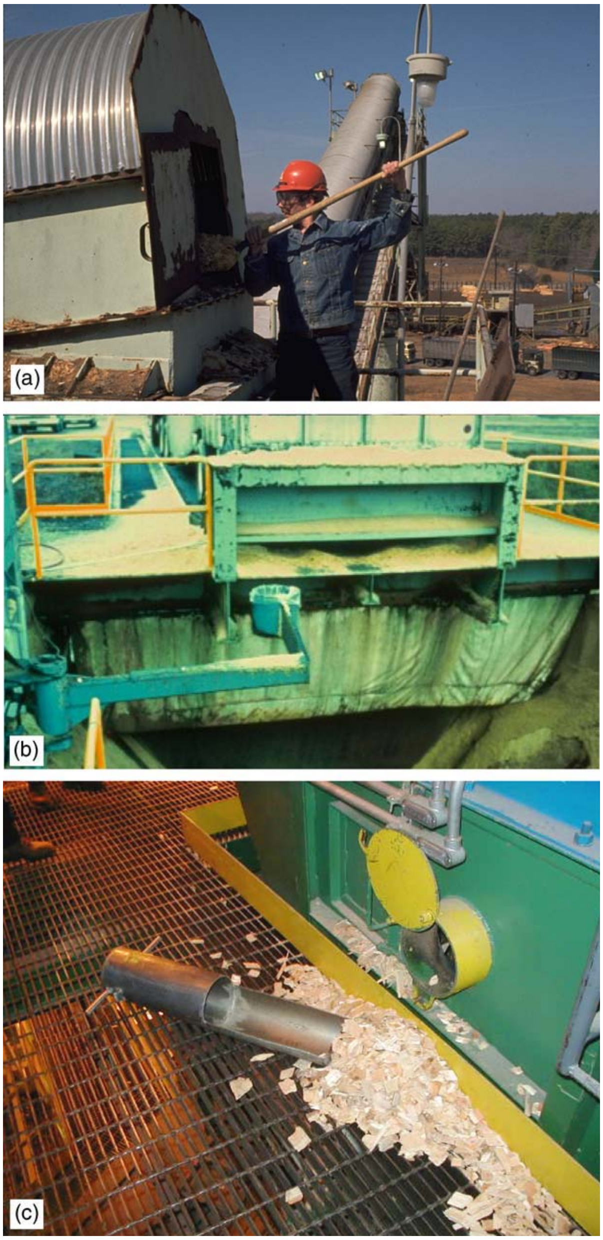

Figure 21 Options for chip sampling. (a) Manual sampling at a belt transfer point using a scoop sized to collect enough chips for the tests being done; (b) an automatic sampler using a bucket mounted on a swinging arm for truck dump sampling; (c) a tube sampler and sample port at a chip screen system to remove chips after screening.

1. Moisture content or %OD (percentage of oven-dry solids) solids. This is used to convert the green weight of chip deliveries to a dry weight. Moisture contents of sawmill and plywood plant residuals, woodroom production, and wood chipped thinnings can differ by as much as 15–20% points. Depending on the mix of wood being used, a pulp mill may be buying a lot of water at chip prices. Factors that influence the reliability of this test were listed earlier.
2. Bark content. The test is a tedious separation of all bark and wood. Optical methods of testing bark have not been successful. To speed the test up, some mills only measure bark in the accepts fraction. This underestimates the actual bark content since up to half of the bark breaks down into small pieces. The need for precise estimates is

diminishing as pulp bleaching technology has made headway in controlling pulp dirt associated with bark that was not removed in sawmill or woodroom debarking. A survey of mills confirmed that the specification for bark has been increasing in recent years from less than 0.5% to 1–2%.

3. Size distribution. There is no agreement on which testing machine and method should be used to describe the size variation in chips. There are two systems that are the most popular. One is currently sold under the trade name Chip Class. It was conceived as part of the Swedish pulping work that demonstrated the importance of thickness in kraft pulping. As shown in **Figure 22**, a series of trays are stacked on a table with linear motion. Each of the fractions has a different importance to the pulping process:

- Over length (retained on a 45 mm hole)
- Over thick (retained on bars spaced 8 mm apart)
- Accepts (retained on a 7 mm round hole)
- Pin chips (retained on a 3 mm round hole)
- Pan (passed through the 3 mm round hole)

An automated version of the Chip Class mounts the classifier trays in a hexagonal drum. The small fractions come out first and weights are accumulated and delivered in a final report by the system PC.

The Rader CC2000 classifier is based on thickness with the ability to separate pin chips and fines (**Figure 23**). Chips are fed into a rotating drum of movable bars. At the beginning of the test, the bars are 2 mm apart and thin chips are extracted. Automated balances weigh the amount of material leaving the drum as the space between the bars is increased in 2 mm increments up to 12 mm. A PC controls the cycles and calculates the percentage in each size classification. Several companies have adopted one or the other as standard size classification methods for their mills.

Figure 22 Chip Class classifier. The classifier next to the Chip Class is the Williams Classifier. It is the earliest classifier that the industry adopted as a standard. It is based on round holes only.

The most critical element of a chip quality control program is the technical staff. Training in test methods should go back to the written method rather than word-of-mouth training. In addition to doing the tests correctly, there must be training to recognize visually what chips should look like, and also to be able to see a problem before the test values are available. It is better to have this person out of the normal progression ladder because experience is vital to the success of a long-term testing program. The testing facilities should be designed specifically for chip testing with good light, heating control, office area for meetings and paperwork, room for all equipment, open area to lay out samples on the floor in sorting and displaying them, and located near the

Figure 23 Rader CC2000 classifier. (a) Two systems allow much more productivity from the chip testing laboratory; (b) like all instruments, it must be periodically cleaned and carefully calibrated.

Figure 24 Chip quality education tool. A display of chip quality definitions, impact on the mill, and real examples of each material type will help suppliers, truck drivers, and others who work with chips to understand the importance of chip quality. Customers of the pulp and paper products will appreciate this example of making chip quality a high priority. The one category missing in this display is emphasis on the requirement to eliminate contamination of chips with metal, plastic, dirt, and rocks.

woodroom. The chip testing position should never be near entry level and the lead tester should be part of the woodroom operating team.

A chip quality report should be more than a stack of computer printouts. In order to be able to see trends and changes, key data should be presented in graphs that are easily interpreted. The graphical reports should be made visible to everyone working in the woodyard and woodroom and discussed with suppliers. With the available spreadsheet graphics programs available, graphing of data should be standard practice. Visual displays focusing on aspects of quality should be developed so that those who deliver chips can know what they should look like, too (**Figure 24**).

Woodyard and Woodroom Safety

Woodyard safety is a critical function for every woodyard employee. Whenever in the operating area, personal protective equipment must be consistently used to reduce the risk of injury. The noise levels around operating debarking, chipping, and screening systems is well above the level that causes permanent hearing loss. Safety glasses with side shields are always needed to prevent wood dust and debris and flying objects from damaging eyes. Hard hats prevent injury from falling objects or head injury in areas with low headroom. When cleaning up dusty areas, respiratory masks will prevent inhalation of small wood particles that can accumulate in the lungs and cause long-term health problems. Some people are sensitive to the molds that grow in enclosed and damp areas such as conveyor tunnels. These people should not be assigned work in the contaminated areas. Equipment that is subject to high stress and impact loads need to be examined periodically. A logjam in the chipper infeed must be cleared to resume production. It is essential that no person place himself or herself at risk of falling into an operating chipper infeed at any time and particularly in this situation. Mechanical systems such as the one shown in **Figure 25** are invaluable in this instance. The rams are pushed in and out to dislodge the jammed logs. If no such device is installed on a chipper, the chipper must be stopped with the use of a disk brake and locked out and tagged out to prevent starting when workers are clearing the chute. Only then should woodroom operators get near the logs in the infeed to attach grapples attached to overhead winches. Log tongs should be attached with both a shackle and a restraining chain in the event the shackle breaks. Normal required lock-out and tag-out procedures are followed to return the chipper to service. Chipper knives are very sharp and should be handled with steel reinforced gloves.

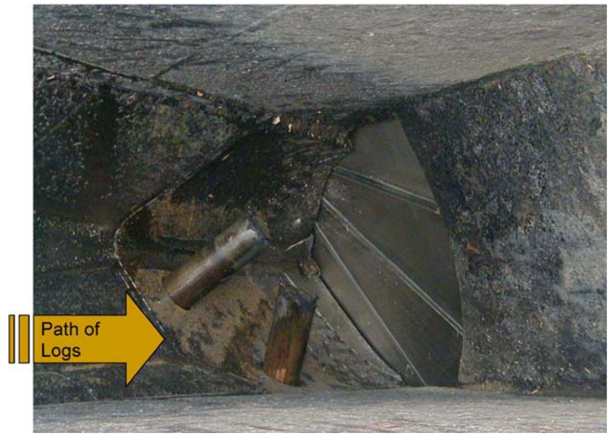

Figure 25 Rams that can be pushed into the chipper infeed to dislodge logs that sometimes frequently plug the spout. This is much safer than trying to break up the jam with pike poles or log tongs and takes less time.

Large mobile equipment and trucks used to transport, store, and reclaim logs and chips have limited visibility and even less in bad weather and at dawn and dusk. If two-way radio communication is possible in the mill, it is good to carry one while working in such hazardous areas. Sign-in and sign-out log sheets are also used to keep track of visitors and workers from other parts of the mill. A short, 10 to 15 minute, safety meeting of woodyard and woodroom operators at the beginning of the work period allows everyone on the crew to hear about special situations, like digging of a large ditch across a woodyard road, and identify and remedy hazards that were observed the day before. With everyone participating, prevention is a lot easier than the consequences of a serious accident.

See also: **Harvesting**: Wood Delivery. **Operations**: Logistics in Forest Operations. **Papermaking**: Overview. **Pulping**: Bleaching of Pulp; Environmental Control.

Further Reading

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Mechanical Pulping

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Introduction

When mechanical action is the principal means for separating fibers from wood, the pulping processes are known as mechanical pulping, and the resulting pulps are mechanical pulps. This section contains descriptions of mechanical pulping processes, products, applications, limitations, and future prospects for mechanical pulps.

Mechanical pulping includes a large number of processes involving mechanical action or a combination of mechanical action and chemical pretreatments that separate fibers from the wood matrix. The main difference between mechanical pulping and chemical pulping is that, in mechanical pulping, the fibers are separated without removing the lignin, whereas in chemical pulping, the lignin is dissolved from the wood using chemicals. Mechanical pulps are characterized by high yield, high lignin content, and relatively stiff fibers that can be bleached to high brightness levels but that will photoyellow (darken) on exposure to light. The yield from the mechanical pulping processes ranges from as high as 98% for some groundwood pulps to about 85% for some of the chemimechanical pulps. In refiner mechanical pulping, the woodchips may be pretreated with chemicals either to reduce refiner energy usage or to help separate the fibers. Compared to chemical processes, the chemimechanical pulping processes remove only a small amount of the lignin in the wood. Since mechanical fibers are stiff and contain large amounts of lignin, these fibers form poor fiber-to-fiber bonds, which decreases sheet strength, but increases sheet opacity and bulk. Because of their high yield and low chemical consumption, these pulps are less expensive to produce and have less impact on the environment than do chemical pulps. The production of mechanical pulps worldwide is about 30% of the total virgin pulp production and is increasing because of its higher yield, lower cost, and less complex environmental concerns. On a per-country basis, the percentage of mechanical pulps ranges from 9.2% of virgin pulp in the USA to 45% in Canada and 62% in Germany.

Usage

The major use of mechanical pulps is in nonpermanent (grades that do not require permanent light-fastness) printing grades. Mechanical pulps are historically used in the following grades: newsprint (newspapers, paperbacked books, magazines), supercalendered magazine (catalogs), and coated mechanical and coated fine paper (commercial printing grades). Depending on the strength properties of the mechanical pulp, newsprint usually contains from 80% to 100% mechanical pulp, with the remainder being chemical pulp added to increase sheet strength. In addition to the nonpermanent printing grades, mechanical pulps are also used in a wide variety of other paper products, including board and tissue/towels. A short description of the major applications for mechanical pulp is presented here.

Newsprint

The quality parameters for newsprint are runnability (low frequency of breaks during printing) and printability (smoothness, opacity, brightness, ink pickup,