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Oats:
Chemistry and Technology

CHAPTER 13

OAT CLEANING AND PROCESSING

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I. INTRODUCTION

The milling of cereal grains is civilization's oldest industry. Primitive people pounded grain upon flat stone or boulder, and for centuries developments were surprisingly slow. The rock on which the grain was crushed tended to become cup shaped, and the pounding stone oval or conical. These gradual changes foreshadowed the mortar and pestle, which were used in ancient Britain and by the aborigines of North America; they were also used in ancient Greece and Rome. The saddlestone, which followed, represented a distinct change from pounding to grinding: kneeling in front of a slab whose shallow concavity suggested the shape of a saddle, the operator, grasping each end of an oval stone having a flat undersurface, would, with a forward and backward rowing movement, grind the grain. Burr mills or stone mills gradually evolved in which the grain was ground between a stationary, circular, flat stone and a rotating stone, the distance between the stones determining the degree of grind.

The history of grain milling from the beginning of time until the last decades of the 19th century is surprisingly monotonous. Such changes as occurred in the industry were in motive power, or method of turning the grinding stones. The progression from human energy provided by slaves and others to energy provided by animals, the use of water and wind power, and finally the steam engine centered, apparently forever, around stone grinding mills. However, during the last decades of the 19th century, roller mills, using either iron or porcelain rolls, very gradually replaced stone mills; they were more efficient and produced more refined and better quality meals and flours.

Inventiveness was not confined to the milling of wheat; as early as 1840, a new device for hulling oats was produced in Camden, Maine. It was not a particularly ingenious machine, being similar to the hullers used in Scotland, where oatmeal in the form of porridge had been a staple of the diet for decades previously. However, its interest lies in the fact that it appears to be the first device intended to improve the oat milling process that was patented in the United States. Other patented developments for improving the cleaning of oats before milling followed, but the first epochal invention in the field of oat milling did not appear until 1875, when Ferdinand Schumacher in Akron, Ohio, patented a cutting machine. Following testing and development, the outcome was a groat-cutting device that instead of converting the hulled kernels of oats (known as groats) into a coarse meal by crushing the grain between rollers or grinding them with burrs or millstones, sliced the kernels into three or four pieces with a minimum production of fine meal or flour. The slicing was achieved by feeding the groats into a hopper with a perforated bottom; the hopper had a free motion above a series of horizontal knives, so arranged that the groats falling endwise through the perforated bottom were sheared off as the hopper moved across them. *Steel-cut oatmeal*, as the product of the new machine was called, quickly became the favorite form of milled oats. Although requiring a longer time to cook than ground meal, it was less exposed (in those days of the open barrel for storage) to the action of the air and was less liable to become rancid.

The ability to cut or slice the oat kernels, rather than crushing them, eventually resulted in the use of roller mills to roll the cut pieces into flakes, generally known now as *rolled oats*. The practice of producing flakes or rolled oats rather than meal evolved on a serious commercial scale during the latter half of the 1800s and had the advantage of converting a much larger portion of the oat kernels into a more valuable product as compared with crushing, which resulted in the formation of a large percentage of fine flour. Also, rolled oats required less cooking time than steel-cut oatmeal, which had practically disappeared for table use by the start of this century. Steam was used as a "binder" to hold the groats intact while being subjected to the rolling pressure, and the application of steam immediately before flaking imparted the added advantage of partially precooking the oats, evolving into the "instant" oatmeal products. Apparently the first registration of these so-called instant cereal products occurred in 1877, with the symbol "3 minute" for application to "steam cooked cereal" (Thornton, 1933).

We have briefly traced the development of milling from the earliest times. During the last century, machine and process design advancements have progressed at a faster pace with the degree of improvement resulting in greater efficiency and better quality products. It is the purpose of this chapter to describe present-day practices and methods of oat cleaning and processing in which some of the basic principles developed by the early pioneers are still applied in a more sophisticated form.

II. OAT CLEANING AND PROCESSING—GENERAL STEPS

The general steps in oat processing are cleaning, hulling, steaming, and flaking (Fig. 1). In the cleaning step, dust, chaff, weed seeds, coarse grains, and other impurities are removed. In the hulling step, oats are graded by size and dried to permit efficient removal of the hull. The hulls are then abraded or knocked off the oats, the dehulled oat (groat) representing about 75% of the kernel. Then the groats are cut into two to four uniform pieces, steamed, and flaked for packaging.

The standard weight per bushel for oats is 32 lb (one Winchester or U.S. bushel equals 2,150.42 in.^{3}, or 35.24 L); the weight can vary from 22 to over 40 lb/bu. Oats fairly free of barley and other grains and weighing about 35–38 lb/bu are

best for milling. Depending on the quality and test weight of the oats, 10–16 bu of oats is required to produce a "barrel" of rolled or flaked oats. A standard oat barrel in the United States is 180 lb (81.63 kg). A fair average test weight runs about 36 lb/bu for milling oats from the Central Plains to 40 lb/bu for oats grown in the western states and Canada. Shrinkage amounting to 4–6% of the purchased oat weight results from drying preparatory to milling. Field oats may contain 12% moisture and are dried down to 6.5%, or less, moisture. Rolled oats contain about 10% moisture and the residue oatfeed by-product about 7% (Loufek, 1944).

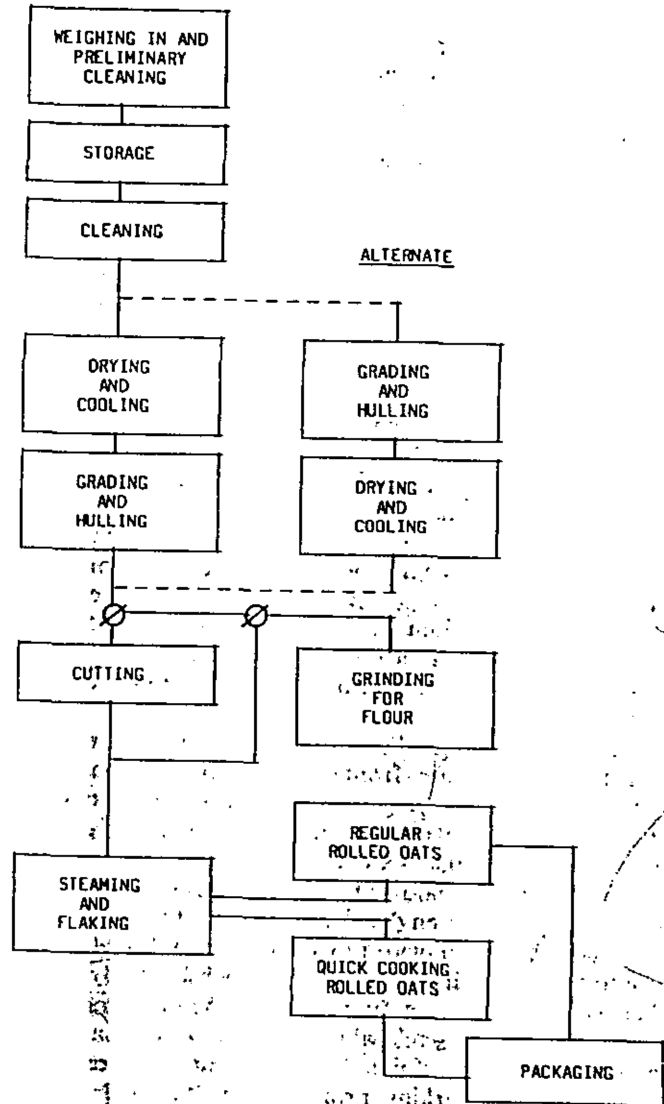


Fig. 1. Flow diagram of steps in oat cleaning and processing.

The following products typically result from milling oats, the percentage breakdown being dependent on the quality of the oats and the overall efficiency of the process: rolled oats, 45–60%; oat hulls, 24–27%; feed oats (doubles, thins, light), 10–20%; mixed grains and seeds (wheat, corn, barley, etc.), 2–3%; and fines (middlings), 2–5%.

III. INTAKE OF FIELD OATS AND PRELIMINARY CLEANING

The purpose of preliminary cleaning is to remove coarse field trash and objects that could damage conveying equipment and to remove dust, loose chaff, and other light impurities before storage.

Field impurities in oats vary widely depending on the location of the processing facility and where the oats are purchased. Some plants encounter impurities that other plants never see, and the preliminary cleaning is, therefore, undertaken on a local basis to suit the prevailing conditions.

When the oats are delivered to the mill, mechanical or electronic scales record the weight for record and inventory purposes. A rough, preliminary cleaning follows to remove coarse objects that could damage subsequent conveying equipment and to remove some of the dust, loose chaff, and other light impurities that cause dust hazards in the storage area and infestation during the storage period.

A receiving separator is used for this initial cleaning step. Generally, the receiving separators use one of two methods to remove the coarse and light impurities. The first method uses slightly inclined wire mesh or perforated sheet metal screens that are given a reciprocating or rotary motion. The perforation openings are selected to let the oats fall through while the coarse impurities are overtailed. The second method uses horizontal, slowly rotating, coarse wire-mesh reels or cylinders. The oats are either fed into the inside of the reel, where the oats fall through while the coarse objects are overtailed, or the oats are fed onto the outside of the rotating reel and pass through while the coarse objects are carried over and evacuated from the machine. The advantage of the latter method of feeding the reel is that the coarse material does not enter the inside of the scalping reel, so there is less chance of it becoming entangled and caught up inside the machine.

Most receiving separators, regardless of model type, incorporate an aspiration channel to remove light impurities from the oats before they leave the machine. Intake rates of the field oats arriving at the plant vary widely depending on the size and production output level of the plant; these can range from a low of 1,000 bu/hr at small mills to over 10,000 bu/hr at large facilities.

Figure 2 shows a receiving separator that is typical of screen-type models. Oats are fed onto the top coarse-screen deck, which is fitted with a perforated metal sheet that is 1 in. long by 1/2 in. wide (25.4 × 12.7 mm). Oats fall through these perforations onto the lower fine-screen layer, which is fitted with a triangular perforated sheet having sides measuring 9/64 in. (3.5 mm). Some fine impurities pass through the lower sieve deck while the oats overtail and pass into the aspiration channel for removal of light impurities, such as loose hulls and dust.

Figure 3 illustrates the working principles of a typical scalper-reel type receiving separator. Oats are feed along the full length of the horizontal main

scalper reel, which is fitted with a 3/4 × 3/4 in. (19.05 × 19.05 mm) wire mesh screen *rotating* at 20 rpm. Coarse objects and long straws are carried over the top of the reel, and the oats pass through the wire mesh to an aspirating channel where light impurities are removed and conveyed to an integral dust-settling chamber. A conveyor then removes these light impurities out of the side of the machine. Coarse material and objects carried over the main scalper reel fall onto a rotating rescalper reel fitted with a 5/8 × 5/8 in. (15.9 × 15.9 mm) wire mesh to recover any oats riding on top of flat material such as paper. The coarse, rejected material falls into a receptacle on the floor adjacent to the machine for subsequent disposal.

The air volume required to aspirate the oats on receiving separators varies greatly according to the oat receiving rate and the size of separator used; it can range from a low of 1,000 ft^3/min (28.3 m^3/min) to a *high* of over 8,000 ft^3/min.

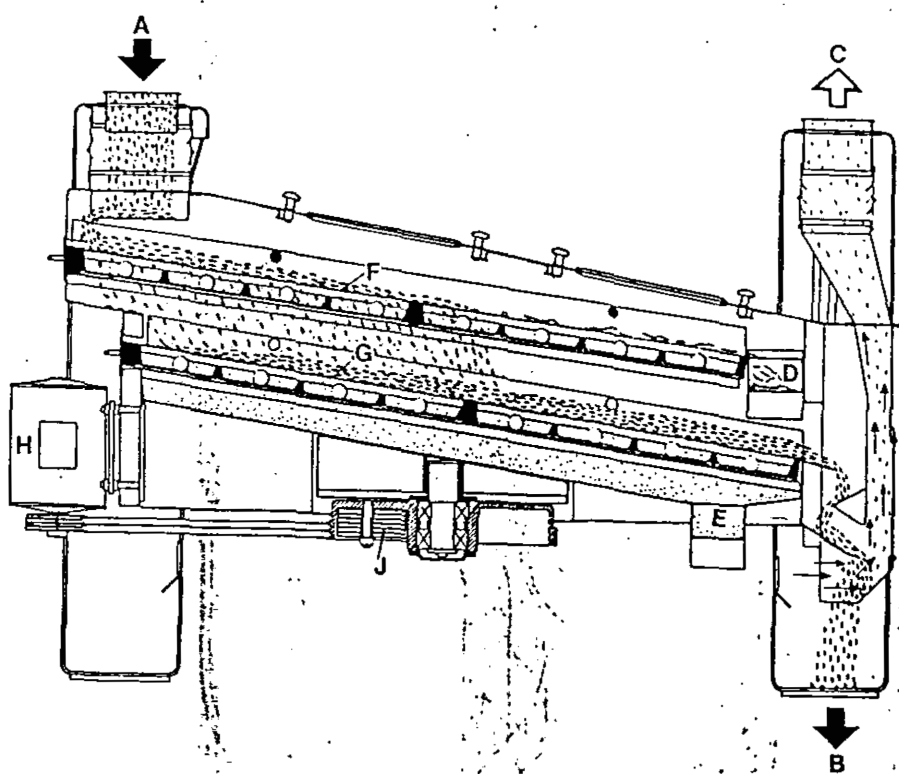


Fig. 2. Schematic of receiving separator. (Courtesy Buhler-Miag, Minneapolis, MN)

(226 m^3/min). Because of present-day high energy costs, many processing companies are now using closed-circuit receiving separators that, by using an integral fan, recycle the aspirating air and drop the removed light material into an internal expansion chamber. This eliminates the need for high-air-volume dust-collecting filter systems and conserves substantially on power costs, as well as reducing equipment capital investment costs.

Incoming oats are evaluated for moisture, test weight, insect contamination, groat discoloration, and milling yield. The rough yield determination is made by screening, hulling, and grading a small sample. The lower the moisture and the higher the test weight of the oats, the better the milling yield (i.e., a greater percentage weight of rolled oats can be produced from a given volume of oats). Insect contamination must be determined before storage so that the oats can be rejected if the contamination level is too high or stored in separate bins to prevent contamination from spreading and to permit the oats to be treated with approved chemicals to kill the insects. After initial testing, the oats are usually binned by yield, degree of contamination, and moisture. Blends are then delivered to the mill to reduce variations in yield and quality of end products.

The benefits of grading oats by milling yield, groat discoloration, moisture, and infestation and of then blending the grades for milling can be considered on the basis of "averaging out" the variations. For example, if those separate grades

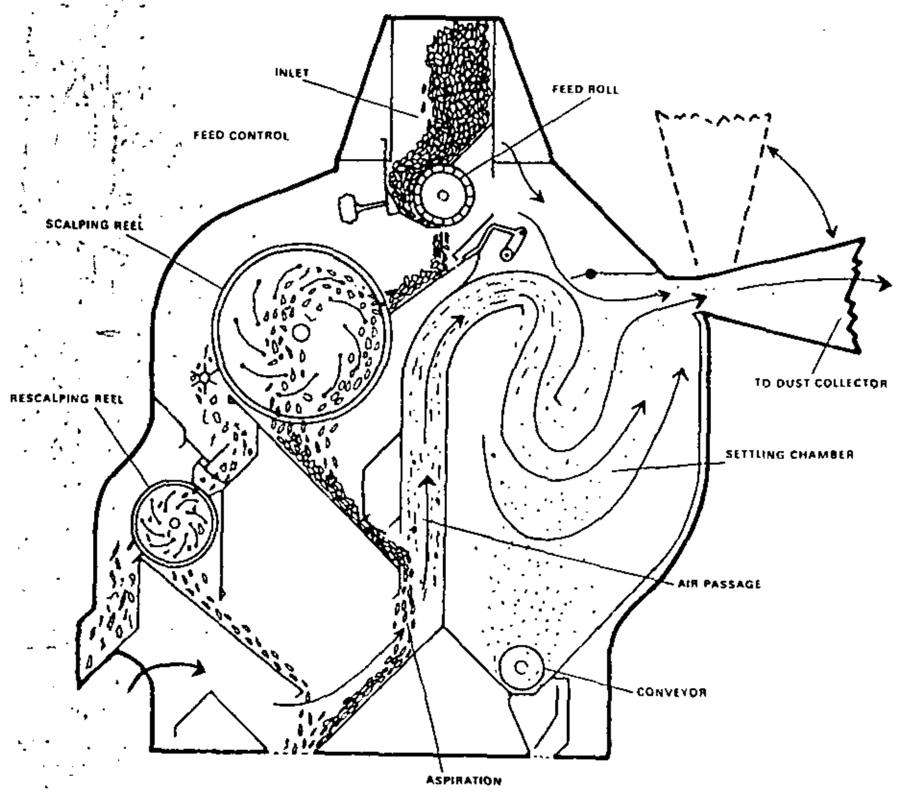


Fig. 3. Schematic of scalper-reel receiving separator. (Courtesy Carter Day Co., Minneapolis, MN)

of oats having test weights of 30, 33, and 38 lb/bu are blended in equal proportions (33-1/3% per grade), the blend for milling will have a test weight of 33.6 lb/bu. By blending the oat grades in suitable proportions, a satisfactory test weight average for milling can be obtained, even though the blend contains a percentage of oats that, on their own, would not give good milling yields. Blending enables commercial advantage to be obtained from the market conditions prevailing at the time the oats are purchased. By maintaining as constant as possible the test weight, moisture, etc., for milling, the end product quality remains consistent and deviations are minimized. Furthermore, process machinery does not have to be readjusted continually to obtain maximum efficiency when the oat quality average remains consistent.

Similarly, some groats are perfectly good but show signs of slight discoloration, resulting in a rolled oat product deviating from the generally accepted and usual flake color. These become considerably less noticeable when blended in small proportions with groats having normal color.

Preliminary cleaning of field oats before storage is only an initial, rough cleaning step, which is not meant to replace the thorough cleaning before milling. It is usually done at comparatively high rates corresponding to the unloading rates from trucks or rail cars. This necessitates the use of coarse screen meshes to achieve the throughput rates, and therefore only coarse objects are removed to protect subsequent conveying equipment and some of the dust, light impurities, and hollow and infested kernels are removed before storage. The total quantity of impurities removed in the initial cleaning stage (coarse trash, coarse and fine impurities, and light screenings) seldom exceeds 0.5% by weight of the incoming oats and more commonly averages only about 0.25%.

IV. OAT CLEANING—SPECIALIZED MACHINES

The initial processing step is the oat cleaning system, the purpose of which is to remove all grain and seed impurities from the oats and also to ensure that all unwanted extraneous material, such as stones, metal particles, sticks, etc., are extracted before milling. Removal of oats that are not suitable for milling is also a purpose of the cleaning stage.

A typical oat cleaning system is illustrated in Fig. 4. The foreign materials removed during cleaning are corn, seeds, sticks, soybeans, barley, wheat, loose hulls, stones, and dust. The contaminants usually become mixed with the oats in the field and during handling in various grain elevators. Oats that are not suitable for milling and that are removed include the following: (i) Double oats (bosom). The hull of the primary kernel envelops the second grain. Normally, groats in both kernels are poorly developed, resulting in a high percentage of hull. (ii) Pin oats. These are usually very thin and short and very poor yielding, with little or no groat inside. (iii) Light oats. Although generally equal in size to normal oats, light oats contain small groats in comparison to the hull; they are separated by aspiration. (iv) Other types of oats. These consist of twins and discolored, green, and hulless kernels, which may or may not be removed in the cleaning plant depending on their size (Salisbury and Wichser, 1971).

The first machine in the cleaning flow is a milling separator combining coarse and fine screening with an efficient aspiration. Different sieve deck motions are available depending on the manufacturer and design concept, and they fall into one of the following categories:

1. Rotary motion in which the sieve moves in a circle in a near horizontal plane. The speed and radius of rotation are interrelated and vary according to the design; with a radius of 1 in., experience has shown that the best speed is around 300 rpm, whereas with a radius of 1-3/4 in., the best speed is about 195 rpm. A rotary motion has a slight tendency to separate products by length as they lie flat on the screen in their passage down the sieve, and the shorter grains pass through the perforations while the longer pieces cannot pass through and are overtailed.

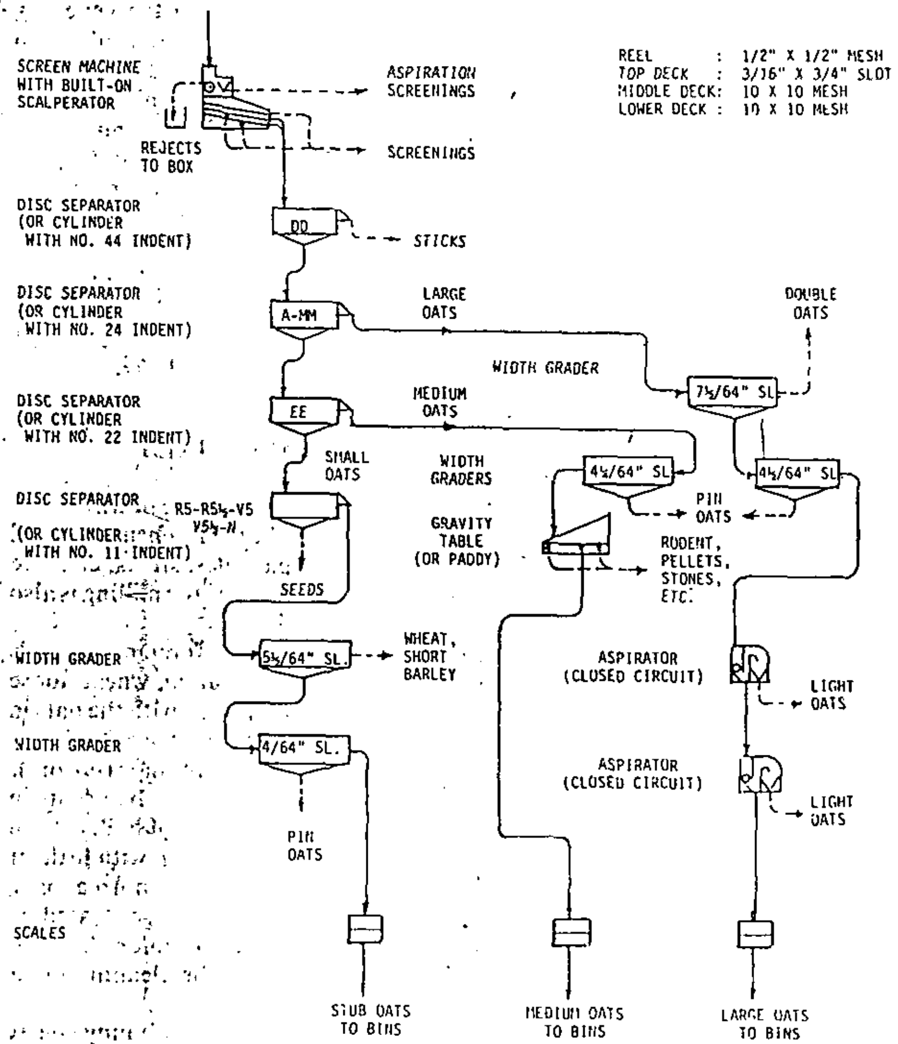


Fig. 4. Typical oat cleaning flow. (Courtesy Carter-Day Co., Minneapolis, MN)

2. Oscillating or *reciprocating* motion in which the sieves slope slightly downward. The speed and stroke of the sieve deck is, again, interrelated for optimum results. For oat cleaning, the range of speed is about 300–450 strokes per minute and the range of stroke about 1/2–1-1/4 in. (12.7–31.7 mm). In general, the higher the speed, the shorter the stroke should be: for example, at 300 strokes per minute the greatest capacity is achieved with a stroke of 1-3/8 in., whereas at 450 strokes per minute the best stroke is 7/8 in. (22.2 mm). The slope of the sieves varies depending on design between 1 in 6 and 1 in 12. Because a reciprocating motion has a tendency to upend grains and material on the sieve, products separate on a width or thickness basis as the kernels are presented longitudinally to the perforations or wire mesh openings when they upend (Lockwood, 1960).
3. Combined head-end rotary motion and tail-end reciprocating motion. This sieve movement combines the advantages of both previously described sieve motions. The rotary, or gyratory, motion has no vertical component, and this allows the product to lie flat and be in contact with the screen at all times. In a reciprocating machine, with each stroke the product is momentarily suspended off the screen, which lowers screening efficiency. With this combination movement, the tail end, or lower part, of the sieves actually reciprocate, which helps move the product down and off the screens and improves product throughput. The gyratory motion is concentrated at the head-end section of the machine where 70–90% of the screening is performed.

In a milling separator, the top sieve deck is clothed with screen material (either perforated sheet metal or wire mesh) to provide a close scalping separation. The oats and fine material fall through the top sieve layer onto the lower sieve layer (or layers) clothed with finer screens for fines removal. Research over the last few years (Carter-Day Company, *unpublished data*) has shown that, for maximum separation efficiency, twice as much fine-screen area as coarse-screen area should be provided because the separation required in the coarse-scalping separation is not normally a near-size one. Therefore, the throughput per square foot of screen is much greater, requiring less screen area for a given capacity rate. In the fine-screening area of the separator, a near-size separation is required, which means that additional screening area is needed to provide time for the fine material and particles to migrate to the bottom of the oat layer, come into contact with the screen mesh, and pass through the openings.

Sieve throughput in a milling separator varies depending on such design parameters as sieve motion, speed, angle of inclination, and depth of product on the sieve. Accordingly, throughput can range from 15 to 27 lb/ft^2·min on coarse-scalping screens and from 12 to 17 lb/ft^2·min on fine screens.

Most milling separators incorporate an aspiration to remove dust and light material from the oats before leaving the machine. Depending on type of separator used, the aspiration is on the oat stream entering the machine on the theory that screening efficiency is improved with preremoval of fines and light material, or else on the oat stream leaving the machine after screening on the theory that the aspiration is more efficient with some impurities removed. Maximum air-volume requirement is about 6.5 ft^3/min per bushel of oats and maximum air velocity in the aspiration channel is about 1,400 ft/min, although these parameters vary according to the machine design.

Figure 5 shows a typical milling separator with built-on scalper-aspirator unit for preremoval of light impurities. This machine is equipped with three screen decks—one coarse and two fine layers, thus incorporating twice the fine-screen to coarse-screen area. Sieve deck assembly motion is the combination head-end rotary and tail-end reciprocating type, and the separations performed result in the following fractions:

1. Scalper reel (wire mesh measuring 1/2 × 1/2 in. [12.7 × 12.7 mm]). Generally, reel rejects consist of straws and coarse foreign objects that may have inadvertently been mixed with the oats during storage or subsequent handling.
2. Scalper-aspirator aspiration. This stream consists of dust, loose hulls, light trash, and poor oats with little or no groats inside.
3. Coarse top screen (over slotted perforation measuring 3/16 × 3/4 in. [3.4 × 19.0 mm]). These overtails usually consist of corn, soybeans, sticks, large weed seeds, and larger stones.
4. Middle and lower fine screens (over 10 wire mesh). These main streams consist mostly of good oats.
5. Middle and lower fine screens (through 10 wire mesh). These fines contain sand, groat chips, and many small seeds.

The next stage of the cleaning process utilizes a series of specialized cleaning machines that selectively remove weed seeds, double oats, any remaining stones or sticks, and low-quality oats such as pin oats. We will first describe the operating principles of these cleaning machines to show how certain types of separations are made, what the limitations are, and how, when operating as an integrated system, they achieve the desired cleaning results.

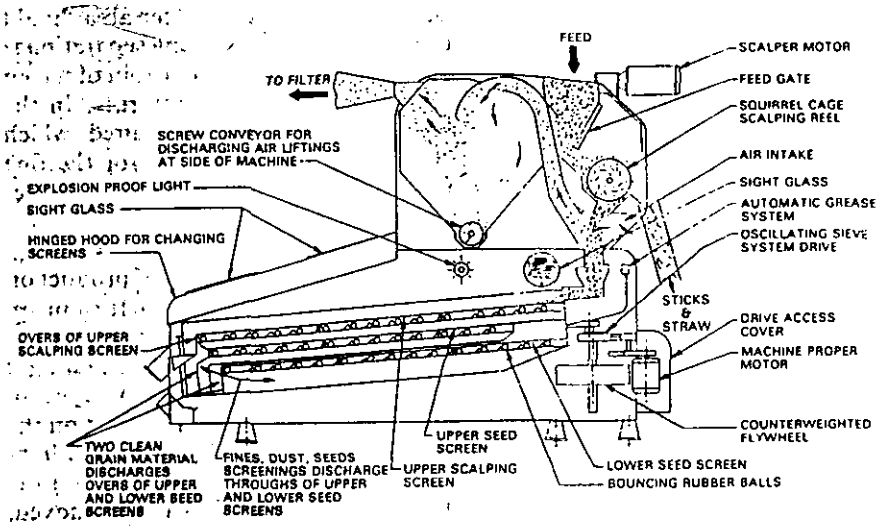


Fig. 5. Schematic of typical milling separator with top-mounted scalper-aspirator. (Courtesy Carter-Day Co., Minneapolis, MN)

A. Disk Separator

Some impurities are the same width or thickness as the oats but differ in length. For example, a round vetch may have the same general width or "plumpness" as an oat kernel, but it is always shorter in overall length. A flat screen removes impurities when the overall dimensions are quite different, but it does not make a precise separation when the dimensions are similar.

A disk separator is specifically designed to perform a separation by differentiating between the difference in length between the desired and unwanted products (Fig. 6). The separator shown consists of a horizontal shaft on which is mounted a series of vertical cast iron disks of 25- or 18-in. (635- or 457-mm) diameter with indented pockets cast in on each side. The disks revolve at 56–58 rpm, which experience has shown to be the best speed to permit grains or seeds to enter the indented pockets and be thrown out of the pockets by centrifugal force when the pockets have rotated past the top center position. A wide range of different indented shapes and sizes is available according to the separation required, and Figs. 7–9 illustrate three of the 52 types of indents that are available. The oats are fed in at one end of the series of disks, and all particles that fit into the indented pockets are lifted out of the mass as it is conveyed through the machine by inclined blades on the spokes of each disk, which attach

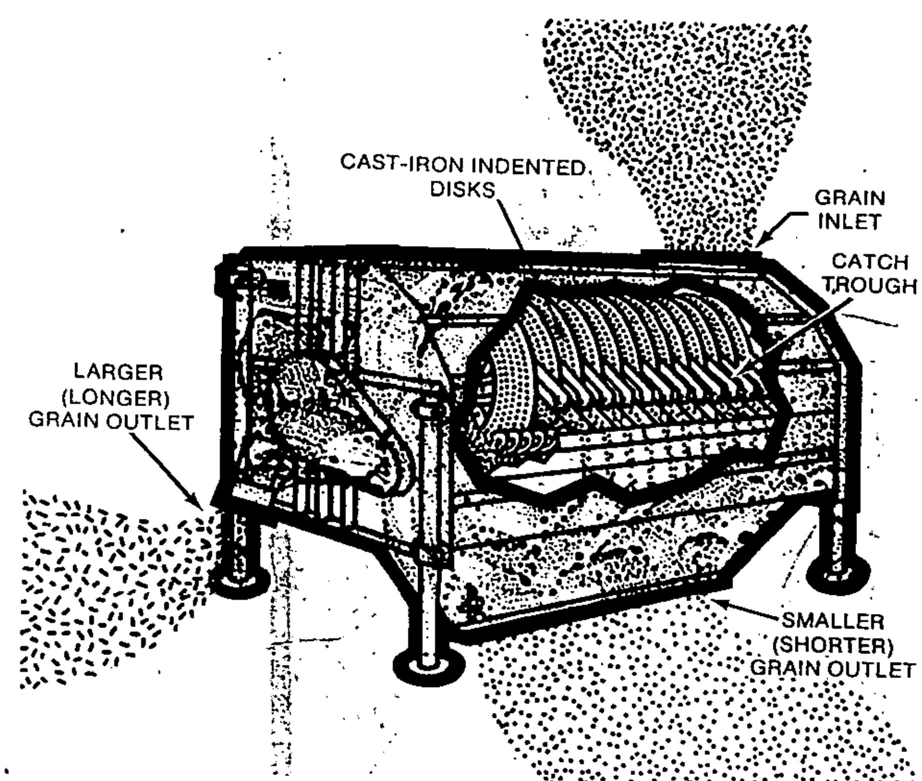
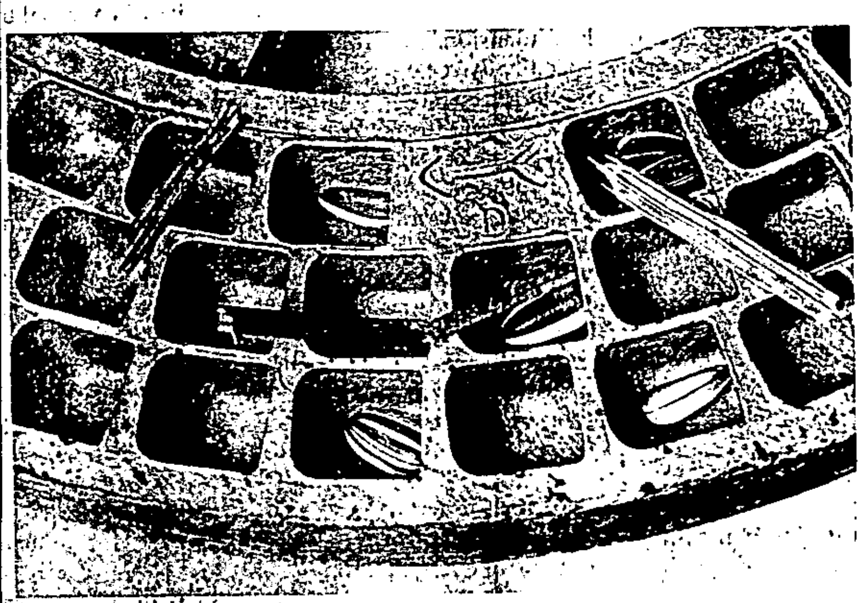


Fig. 6. Schematic of disk separator. (Courtesy Carter-Day Co., Minneapolis, MN)

e indented pocket section to the central shaft; the product mass literally passes own the machine between the spokes from one disk to the next. The larger articles, or grains, do not fit into the indented pockets and are conveyed down e machine, from disk to disk, by the inclined blades until they reach the last



ig. 7. Disk pockets—sticks being removed from oats (sticks longest).

Fig. 8. Disk pockets—oats being removed from wheat (oats longest).

disk and are overtailed from the disk machine through an outlet at the tail end. Small particles that fit into the indented pockets and are lifted out of the mass are thrown out onto catch troughs between the disks when the indented pocket has passed top center position on the disk rotation (much as grain is thrown out of bucket elevator cups when the cups have passed over the top of the head pulley). The lifted product slides off the catch troughs into a collecting hopper running the entire length of the machine.

In a disk separator, the shortest product is always lifted by the indented pockets and the longest product is rejected by the indents and overtailed. Hence, large indented pocket disks lift oats out of larger impurities such as sticks, and small seeds are lifted out of oats with smaller indented pocket disks. To make a good separation, there must be at least 1/16-in. (1.6 mm) difference in length between the products to be separated.

In a typical disk separator (27 disks, each with a 25-in. [635-mm] diameter) used for separating seeds out of oats using R5-1/2 size indented pockets, there are 8,596 indented pockets on both sides of each disk, or a total of 232,092 indented pockets in the machine. The number of indented pockets coming into

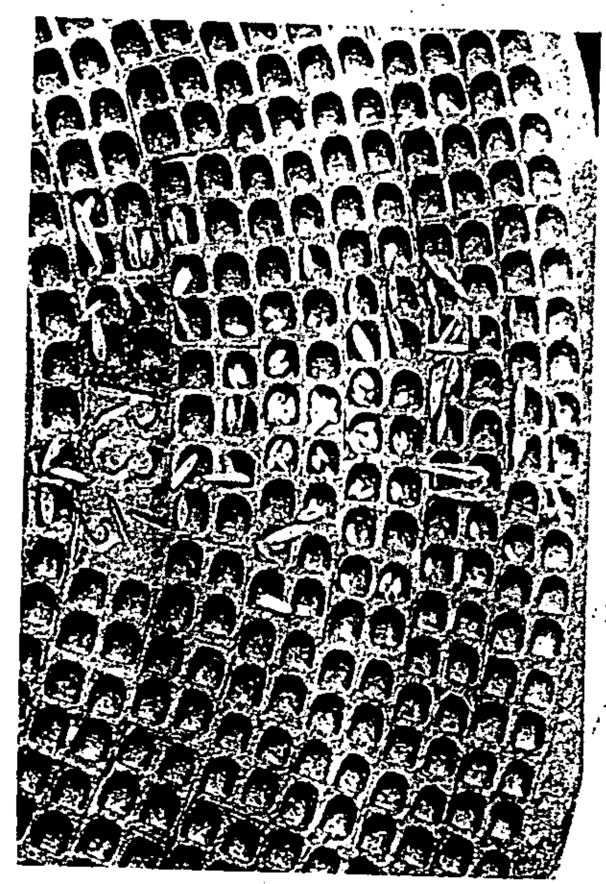
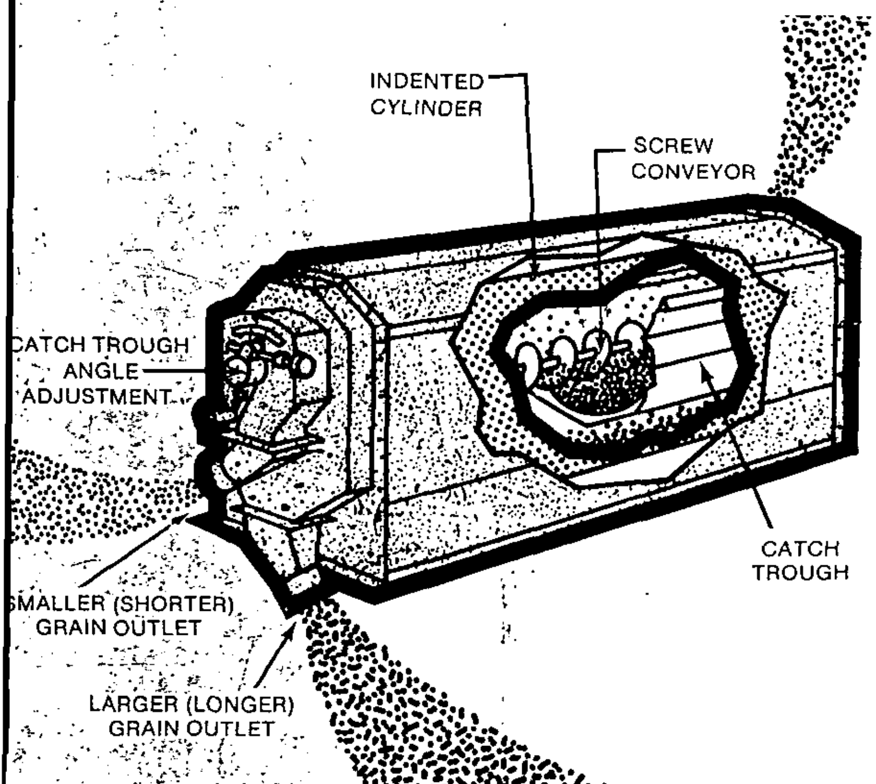


Fig. 9. Disk pockets—seeds being removed from oats (seed shortest).

ntact with the oats during each minute of operation at 56 rpm disk speed is ,997,152. This size of machine has a maximum capacity of 200 bushels of oats r hour.

B. Indented Cylinder

A second type of separator is an indented cylinder separator that performs the me length separation of particles as a disk separator (Fig. 10). This machine has lowly rotating (56 rpm), horizontal cylinder with indents punched in the inner rface. The indents lift the shorter particles out of the mass and drop them into a tch trough with a screw conveyor in the bottom, positioned down the center of e cylinder, from where they are conveyed out of the machine; Fig. 11 shows the dented cylinder drum surface. The longer particles, which do not fit into the dents, overtail out of the end of the cylinder. Hence, small seeds can be lifted t of oats with smaller indents and oats can be lifted out of longer sticks with ger indents. The angle of the catch trough in relationship to the rising side of e cylinder can be adjusted with the machine in operation, and thus the "cut int" of the separation can be selected to provide the separation required. The ass of product entering the indented cylinder tends to ride up on the rising side the cylinder because of friction, but any particle that does not fit into the



g. 10. Schematic of indented cylinder separator. (Courtesy Carter-Day Co., Minneapolis, MN)

indents eventually falls back into the mass as a result of gravity. By positioning the edge of the catch trough lower down the rising side of the cylinder, more longer particles have the opportunity to ride up and fall into the catch trough. By raising the edge of the catch trough higher up the rising side, only shorter particles that fit snugly into the indents are able to fall into the catch trough and be separated from the mass.

This flexibility of separation adjustment is helpful for more difficult separations, such as lifting large barley out of short oats when the length of the two grains is similar but not identical. Indented cylinder separators have lower capacities than disk separators, and hence more machines are required for a given flow rate. Capacity is reduced because there are fewer indents in a single cylinder than there are indented pockets in the series of disks in a disk separator. For example, the total number of comparable indents to the disk pockets in the Model 2527 disk separator discussed previously is 89,100 on a No. 3 Carter Uniflow Cylinder Separator; this compares with a total of 232,092 indent pockets on the disk machine. In general terms, the capacity of an indented cylinder separator is about one-quarter that of a disk separator on similar applications.

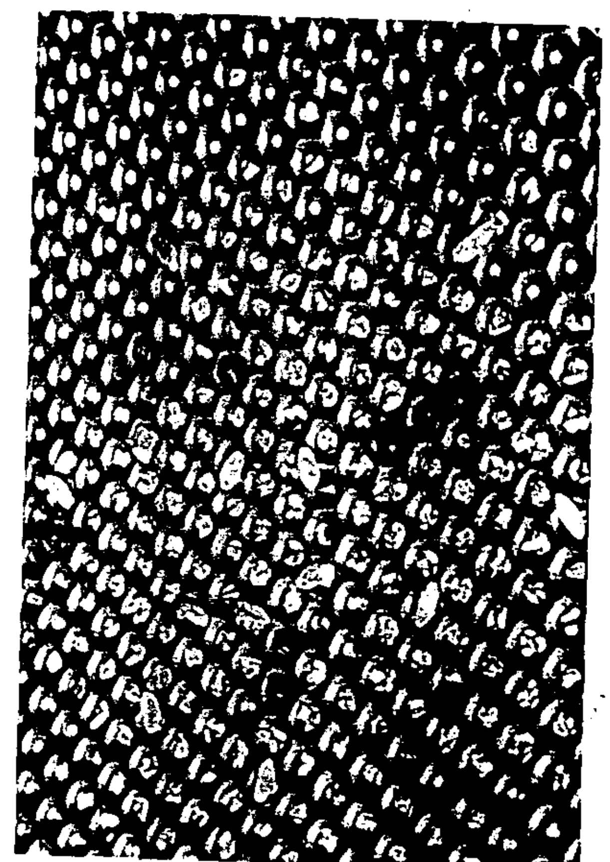
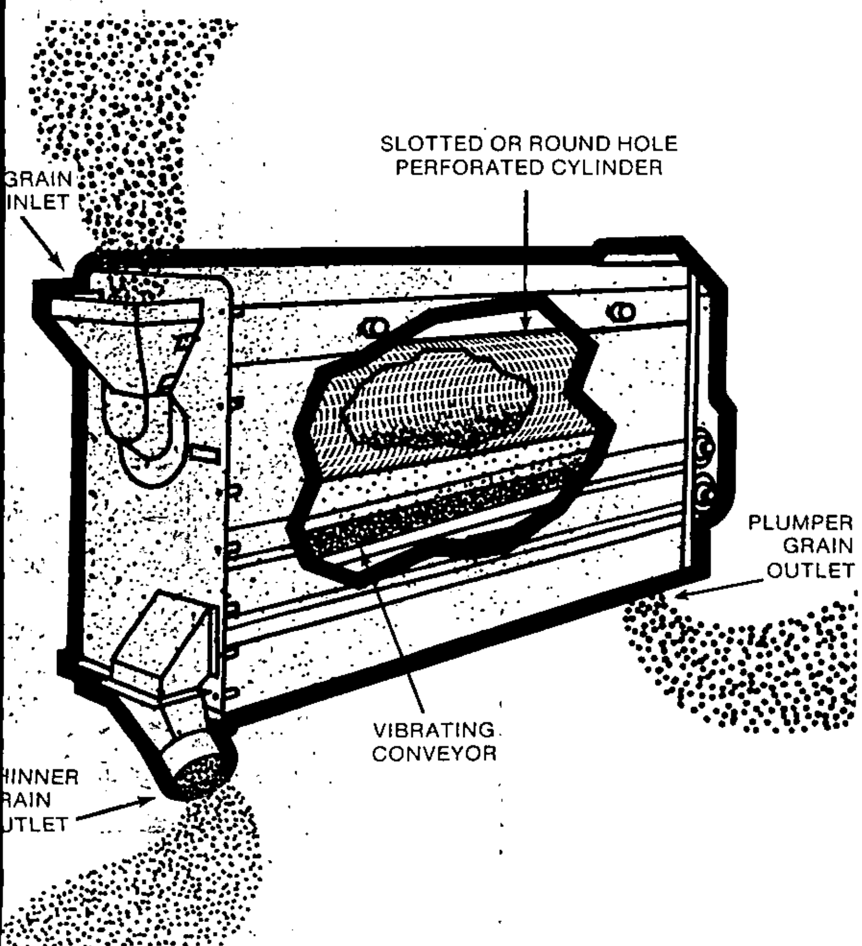


Fig. 11. Indented cylinder drum surface.

C. Width Sizer

he width or thickness sizer (Fig. 12) separates grains when their length is the e but their width or thickness (plumpness) is different. It consists of a slowly ting (56 rpm), horizontal cylinder with round hole perforations (Fig. 13) or angular slots (Fig. 14) cut in. In cylinder shells with round hole perforations, small perforation sizes (3/64–3/16 in. [1.2–4.8 mm] diameter) have internal placed lengthwise down the cylinder between each several rows of orations, and the larger sizes (13/64–27/64 in. [5.2–10.7 mm] diameter) are essed (i.e., the hole is at the bottom of an indent). Slotted cylinder shells have rectangular slots in rows, with the long side of the slot running around the ll circumference (Fig. 15). Perforated slot sizes are available in a range from /64 to 20/64 in. [1.0 to 7.9 mm] wide.

hen slotted perforations are used, channels or grooves upend and align the d or other grains presenting the *thickness* of the seed to the opening. If



12. Schematic of width or thickness sizer. (Courtesy Carter-Day Co., Minneapolis, MN)

sufficiently thin, they then fall through the slotted perforation at the bottom of the groove while oversize grains, which are unable to fall through, pass down the inside of the cylinder shell and overtail through an outlet at the tail end of the machine. The thinner products passing through the cylinder slots are conveyed by a vibrating conveyor under the cylinder to an outlet at the end of the machine.

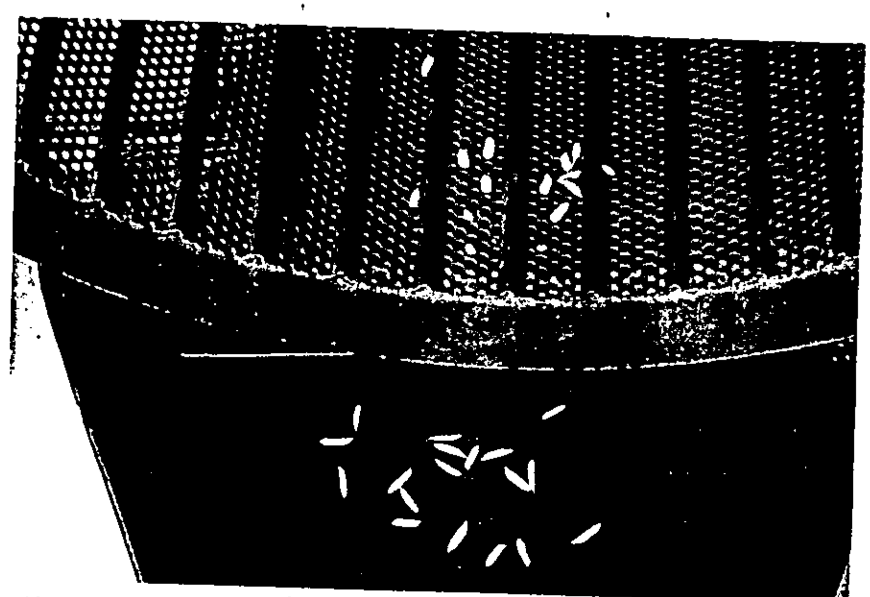


Fig. 13. Round-hole ribbed cylinder shell.

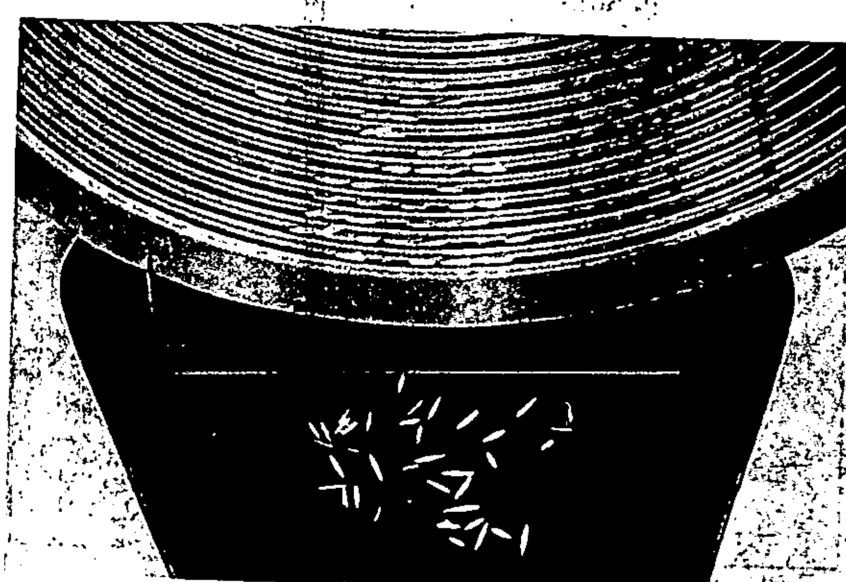
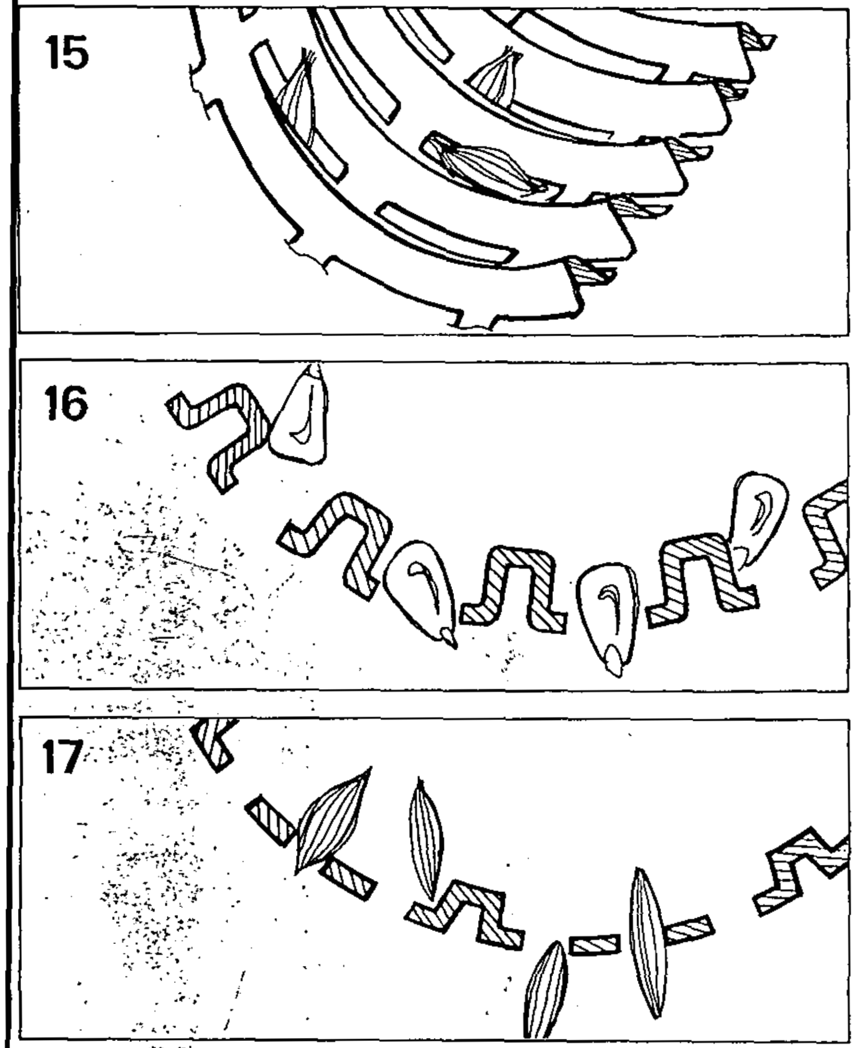


Fig. 14. Slotted cylinder shell.

ylinder shells with recessed round perforations (13/64–27/64 in. [5.2–10.7] diameter) are used for *width* sizing (Fig. 16). The recess or indent at the top he perforations causes seed or other grain to upend, presenting the diameter *vidth of the seed or grain to the opening that enables seeds, etc., to fall through* perforations.

he ribs in the small round-hole perforations (3/64–12.5/64 in. [1.2–5.0 mm] meter) agitate the materials and upend them to present the product diameter he perforation in much the same fashion as the recessed indent does in the er size perforations (Fig. 17).



gs. 15–17. Schematic of (15) slotted cylinder shell, (16) round-hole recessed cylinder shell, and (17) nd-hole ribbed cylinder shell. (Courtesy Carter-Day Co., Minneapolis, MN)

D. Gravity Separator

Some impurities have very similar length and width characteristics to oats and, therefore, they cannot be accurately separated by the length- or width-sizing equipment just described. Such impurities as oat kernels slightly hollowed because of insect damage and sticks the same length and width as an oat kernel come into this category. Many of these impurities are, however, lighter or heavier than oats and thus have a different specific gravity. The term *gravity separator* is a contraction of the proper name of this machine, *specific gravity separator*, which means a separator of particles differing in their specific gravities.

About 250 B.C., Archimedes discovered the law of specific gravity, which states that all bodies floating on or submerged in a liquid are buoyed up by a force exactly equal to the weight of the liquid they displace. The specific gravity of a particle is the ratio of its density to some standard substance, the standard usually being water with a specific gravity of one. Particles having a specific gravity of less than one will float, and those with a specific gravity of greater than one will sink. All gravity separators use air as a standard rather than water; since air is lighter than water, the relative difference between particles of differing weights is increased. For this reason, the gravity separator is a very sensitive machine that, when operated correctly, can produce a very precise separation.

Air is used as the separating standard through the process of stratification (Fig. 18). Stratification occurs by forcing air through the particle mixture so that the particles rise or fall by their relative weight to the air. Figure 18A represents a cross section of a gravity separator directly over the fan; a particle mixture has been introduced on top of the screen deck with the fans off. In Fig. 18B, the fan has been turned on and adjusted so that the heaviest particles rest on the surface of the deck and the lightest particles are completely free of the surface of the deck. Proper regulation of the airflow at this time is critical or, as shown in Fig. 18C, all particles are lifted free of the separating deck surface by excess air. Figure 19 shown the ideal situation in the operation of a gravity separator.

The particle mixture, oats containing lighter and heavier impurities (similar to the situation shown in Fig. 18A), falls from the feeder onto the deck. The area

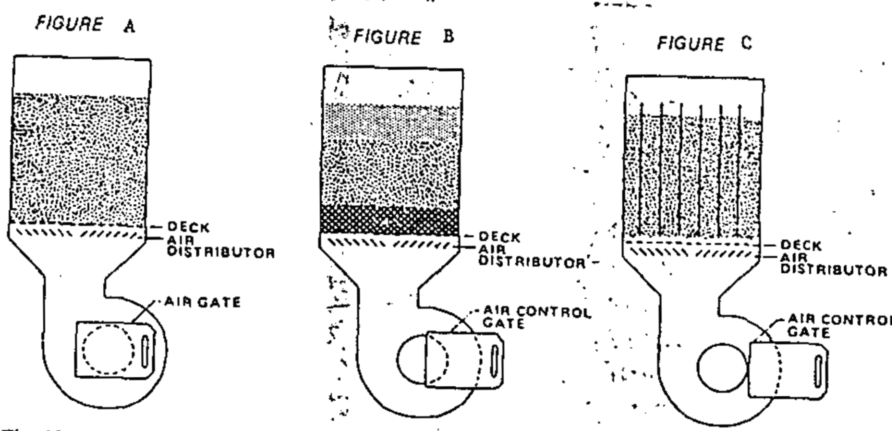


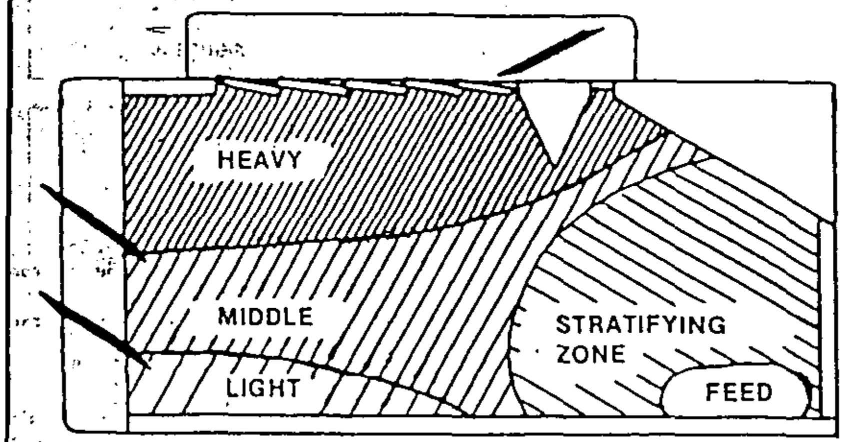
Fig. 18. Principle of stratification. (Reprinted, with permission, from Oliver Manufacturing Co., undated)

mediately around the feeder is called the stratifying area, where the vibration the deck and the lifting action of the air combine to stratify the material into ers, with the heavier layers, such as stones, on the bottom and the lighter ers, such as hollow weed seeds or hollow oats, on the top (Fig. 18B). paration cannot occur until the material becomes stratified. The size of the atification area depends on the difficulty of the separation and on the capacity which the machine is processing. Once the material becomes stratified, the rating action of the deck begins pushing the heavier layers in contact with the k toward its high side. At the same time, the lighter layers, which are at the top the material bed and do not touch the vibrating deck, float downhill toward low side of the slightly sloping deck.

As the material flows downhill from the feed end to the discharge end of the k, the vibrating action gradually converts the layers of vertical stratification a horizontal separation. By the time the material reaches the discharge end of deck, the separation is complete. Heavier materials, such as rocks and stones, concentrated at the high side of the gently sloping deck. Light materials, such hollowed weed seeds, are at the low side of the deck, and intermediate terials, the good oats, are in between. Movable vanes at the discharge end of deck are adjusted to give the desired cut point between the three fractions liver Manufacturing Co., undated).

E. Paddy Separator

When known mechanical methods such as sieves, aspirators, and length, dth, and thickness grading fail to separate effectively, different materials of arly equal size, shape, and almost equal specific gravity can be separated by a ddy separator. Gravity separators are limited in their ability to make a precise paration when the specific gravity of the particles to be separated is almost entical. The concept of the paddy separator was based on a discovery, made by ederic H. Schule in Germany in 1892, proving that grains, although almost



g. 19. Ideal situation in operation of gravity separator. (Reprinted, with permission, from Oliver anufacturing Co., undated)

equal in size and shape, may vary with regard to specific gravity, surface texture, and effect of *gravitation*.

The tendency to settle depends on the difference in specific gravity (however small), surface smoothness, and grain shape. Thus, hulled oats are smoother and weigh more, so they travel down the table while the grains with husks still on them, which are rougher in surface texture, travel upward (Fig. 20). The table, which is made to pivot around its longitudinal axis, rests upon rubber tires. Sorting takes place within the compartments, being affected by a series of zigzags arranged at right angles to the direction of motion.

The oats to be treated accumulate in the separating compartments, forming a mound of a certain height above the channel bottom with the layer diminishing in thickness toward the discharge areas. If the compartments are correctly fed, the shaking motion of the table causes the *formation of layers in a vertical direction* according to the physical properties of the different grains (hulled and unhulled oats), with the top layer consisting (to a large extent) of the larger and lighter kernels (unhulled) and the bottom layer consisting of smaller, yet specifically heavier *grains (hulled)*.

Apart from the formation of layers and the preseparation, the varying surface texture of the kernels affects the separating process. Following the table slope and gravity, the grains tend to travel toward the lower side (discharge of heavy kernels). The impact imparted to the grains by being thrown against the channel flanks, which are arranged at an angle of 28° to the direction of table movement, causes the grains, especially those of the top layer (unhulled), to travel toward the upper side (discharge of light kernels) (*Fig. 21*). *The knee in the channel* is indispensable for an efficient separation. Width of channel, length of stroke, and acceleration of the deck have to be precisely adjusted to achieve optimum separating efficiency and peak capacity (F. H. Schule GMBH, undated).

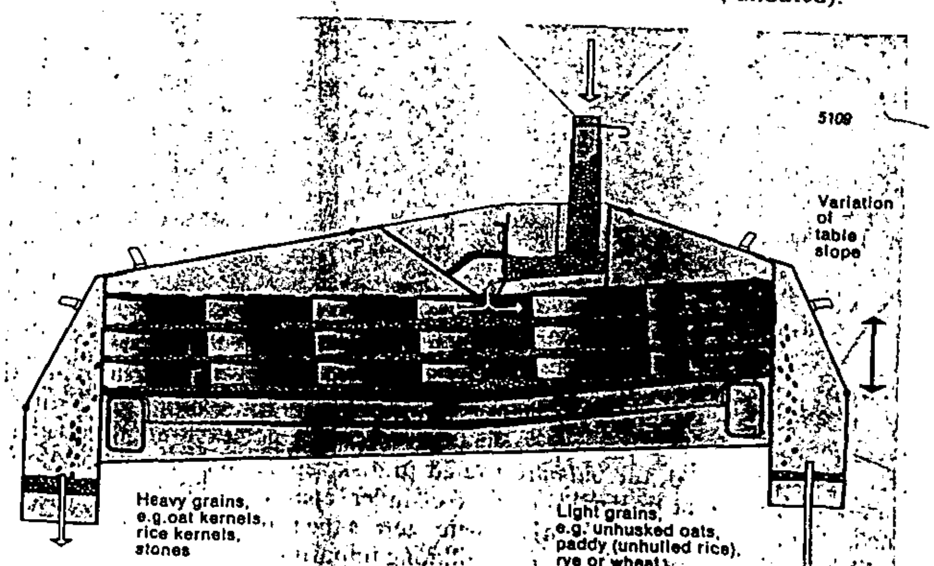
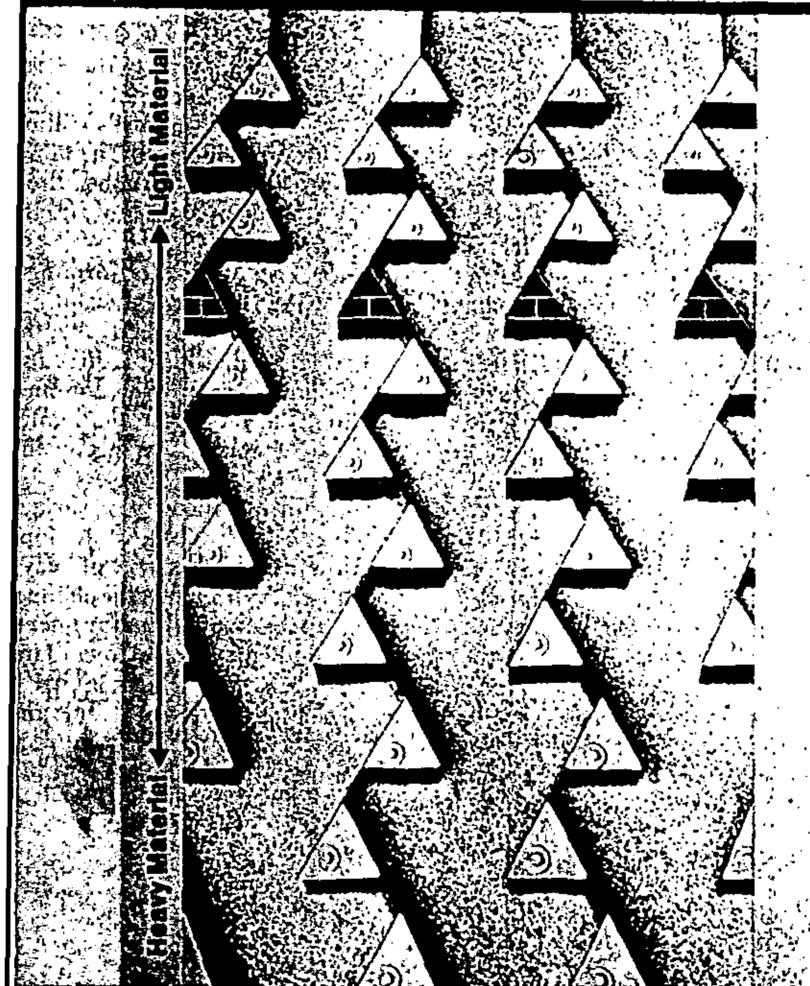


Fig. 20. Sectional view of separating table. (Reprinted, with permission, from F. H. Schule GMBH, undated)



ig. 21. Channel flanks. (Reprinted, with permission, from F. H. Schule GMBH, undated)

V. FURTHER OAT CLEANING AND GRADING

We now return to the initial aspirating and screening performed on the milling eparator and continue with the oat cleaning and grading process that ncorporates some, or all, of these specialized machines. After the initial cleaning tep (refer to Fig. 4), the oats are routed to disk separators where sticks are emoved by DD type disk pockets (or to cylinder separators with No. 44 indent hells—e.g., 44/64-in. [17.5 mm] diameter across the top of the indent) that lift ut the good oats and reject, or overtail, long impurities.

Following stick removal, the aim is to classify the oats into the three fractions f stub (short) oats, medium-size oats, and large oats so that each fraction, which

contains its own particular types and sizes of impurities, can receive individual cleaning treatment more selectively and more efficiently than if all sizes were kept together as one mixed stream. The oats go to another disk separator with A and MM pockets (or cylinders with No. 24 indents) that separate large oats from the shorter medium-size and small oats; the last two fractions contain all the weed seeds present because these seeds are considerably smaller, or shorter, than the large oats. The pockets lift out all the seeds with the medium-size and short oats and reject and overtail the large oats. The larger or longer oats rejected by the A and MM pockets (or No. 24 indents) next pass to a width sizer fitted with a 7.5/64-in. (3.0-mm) slotted cylinder that permits good oats to fall through and overtails the double oats not suitable for processing. Pin (thin) oats are then removed by a slot that is 4.5/64 in. (1.8 mm) wide on a second width sizer. The good, large oats then receive a two-stage aspiration on multilouver or on closed- or open-circuit aspirators to remove light oats. Following aspiration, the large oat stream is weighed and binned. Some processors prefer to use gravity separators at this point instead of aspirators to remove light oats and also to ensure removal of any heavy impurities, such as mud balls or stones, that may be present and that aspirators will not separate.

The mixture of medium-size and small oats lifted by the A and MM disk pockets (or No. 24 cylinder indents) flows to another disk separator fitted with EE type disk pockets (or a cylinder with No. 22 indents), which reject or overtail the medium-size oats and lift out the small oats containing weed seeds, some groats, wheat, and short barley. The seeds are then removed from the small oats by another disk machine equipped with a variety of R5, R5-1/2, V5, and N pockets (or a cylinder with No. 11 indents). The small oats from this separator pass to a width sizer with a slotted cylinder shell 5.5/64 in. (2.2 mm) wide that permits the oats to pass through and overtails any wheat or barley present. A final width grading is made on a 4/64-in. (1.6-mm) slotted cylinder shell to drop pin (thin) oats through before the good, small, or stub oats are weighed and binned.

The medium-size oats separated earlier by the EE disk pockets (or No. 22 indents) are routed to a width sizer with a slotted cylinder shell 4.25/64 in. (1.7-mm) wide to remove any pin (thin) oats present. The medium-size oats then proceed to a gravity separator that removes light rodent pellets and any other light impurities present, such as similar-size weed seeds, the lighter of which have been hollowed out by insect damage or lack of development; this separator also separates out any heavier stones. A specific gravity separation is used at this point because the impurities to be removed are generally of similar length and width to the oats. They are, however, lighter or heavier, which permits a well-adjusted gravity separator to make a good separation. As described in the section on specialized machines, a combination of sieve deck inclination, speed, throw (amount of horizontal movement), and a high volume of air passing through the screen deck to achieve stratification is used to achieve the separation. A very careful adjustment of all these settings is required to obtain effective results on a specific gravity separator. The medium-size oats from the gravity separator are weighed and binned.

At this point, the oats—which have been cleaned, sized, and put into storage bins—are ready for hulling. The percentage breakdown of each size naturally varies depending on the place of origin of the oats and the growing-season nditions, but a typical breakdown would be 30–35% large oats, 45–50% dium-size oats, and 20–25% stub oats.

It is customary to have magnetic separations in the cleaning and sizing steps to nove ferrous metal particles from the oats. Such particles, consisting of nuts, lts, and rivets, etc., may be present in the raw oats delivered to the mill or have come detached from machines during processing. Magnetic protection is ovided by permanent spout magnets, electromagnets, or rotating drum gnets positioned so that the stream of oats entering and leaving the cleaning tem passes over them.

In a commercial operation, the machinery used varies depending on the pacity or flow rate of the system. Larger plants contain several machines erating in parallel on each particular separation, whereas smaller plants may ve only one or two machines. Also, the disk pocket selections, cylinder indents, d width-sizer slotted cylinder shell sizes given above are intended to be typical; ferent processors may use variations, as well as different approaches to the ual cleaning flow. Indented cylinders may be used instead of disk machines on me or all of the length separations (see Fig. 4). Regardless of the approach ken, the desired end result remains the same—namely, to produce well-cleaned ts graded according to size for hulling, which, as the name implies, entails noval of the hull or husk. Before hulling, however, the oats are dried.

VI. DRYING AND COOLING

Hulled oats, or groats, contain about 6.5% fat, a quantity that is not found in y other cereal grain. During normal storage of oats, for example, at 13% oisture and up to 65° F (18° C), free fatty acid content increases only very owly; but if the oats are crushed or milled into meal, the production of free fatty id is considerable in a matter of two or three days. The catalyst in the oduction of free fatty acid is an enzyme of the lipase type. Free fatty acid causes e product to become rancid and unpalatable; however, if the oats are subjected heat, the lipase is inactivated within a few minutes provided the moisture does t fall below 12% and the oats are maintained at a temperature of 194–212° F 0–100° C).

The next step in the oat processing system is, therefore, drying and cooling. e objectives of this stage are to inactivate the lipase or fat-splitting enzymes fficiently to prevent the development of undesirable flavors during processing d to prevent rapid rancidity in the end product (Hutchinson et al, 1951); to velop a slightly roasted flavor, which is considered desirable by most ocessors; and to make the oat hulls more friable, or brittle, to facilitate their moval during the subsequent dehulling stage.

Different approaches to drying and cooling are taken by processors according their individual preferences and market requirements. One older method is to e pan dryers, which are normally about 12 ft (3.6 m) in diameter and placed e above the other in stacks of 7–14 pans depending on the capacity and tention time required; each pan is steam jacketed and open on the top. A tention time in the stack of at least 1 hr of drying is usually required to achieve e desired degree of flavor development. The oats are moved from the inside to e outside of each pan by sweep arms, and they move through the system by opping from the outside of the top pan to the inside of the pan below (Fig. 22).

Temperature of the oats usually ranges from 190 to 200° F (88 to 93° C) during drying, and normally only 3–5% moisture is removed. Oats entering the dryer average around 12% moisture content and are in the 7–10% range leaving the dryer. During the drying process, by the time the oats reach a temperature of 190–200° F (88–93° C), the moisture content has fallen below 12%; when the oats are cooled, they still show some 20–40% of their original lipase activity. The oat steaming process, which is described in a later section, completes the inactivation of the lipase.

Another form of oat dryer is the radiator column type, in which a vertical column has banks of horizontal radiators arranged down the height of the column in a staggered fashion so that all the oats come into contact with the steam-heated surfaces in their slow passages down and through the radiators.

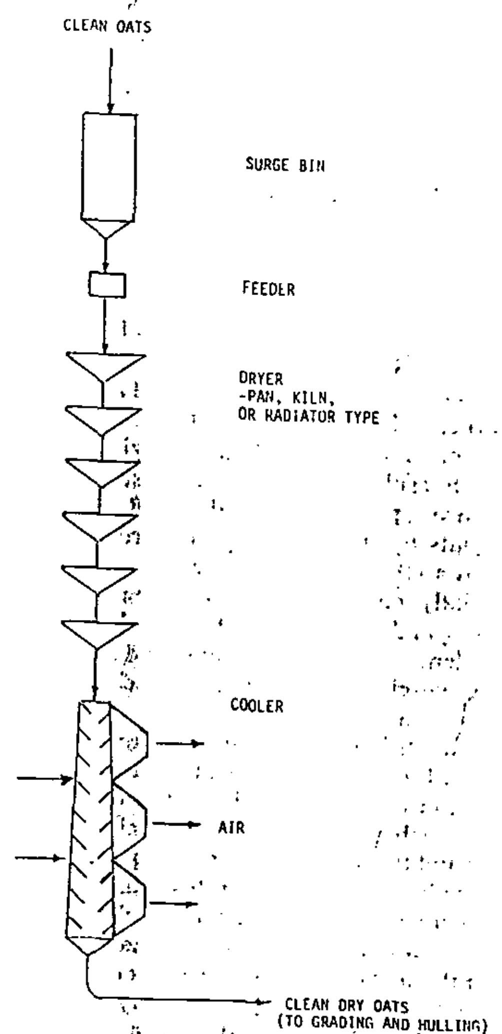


Fig. 22. Flow of oat drying and cooling system. (Courtesy Carter-Day Co., Minneapolis, MN)

naller-capacity mills sometimes use rotary steam dryers, but generally the vor development is considered lower than in pan or radiator column dryers cause the retention time is much reduced. Many European processors use arcoal-fired kilns, in which the combustion gases passing through the oats part a distinctive roasted flavor to the oatmeal.

Some mills are now drying (with kilns, pan, or radiator type dryers) later in the ocess after the hulls have been removed from the oats (i.e., groat drying). It is aimed that the groats are tougher because they have not been dried at the hulling stage and, therefore, that the tips do not suffer as much damage in the llers. Consequently, a higher yield is claimed (about 1–5% more), and the husk at a higher moisture level since it has not been dried out, giving a higher weight -product with a greater commercial value.

Following drying, the oats are cooled for further processing, usually on ultilouver-type cooling columns or in a cooling section on the bottom of diator dryers, in which ambient air is drawn through the oats to reduce mperature. Leaving the cooler, the oats have a moisture content of about 11% and a temperature in the 100–120° F (38–49° C) range.

VII. GRADING AND HULLING

After the cooling stage the oats are ready for hulling, which, as the name plies, separates the outside hulls from the groats inside the kernels. (Where oat drying is practiced, the hulls have been removed following cleaning.) The lls must be removed because they are tough, lack flavor, and are unpalatable r human consumption. Hulling efficiency is improved by prior grading or ing of the oats so that each hulling machine is fed a limited, rather than wide, nge of kernel sizes (i.e., either longer or shorter oats, but not a mixture of both es). In the system previously described, the sizing was carried out in the eaning process, which resulted in large, medium-size, and small (stub) grades; me processors, however, prefer to clean, dry, and cool the oats as one stream d then grade the oats by size on a separate processing system just before lling. Figure 23 shows a typical grading flow for hulling when this approach is ken, which essentially constitutes the head-end grading section of the mprehensive cleaning and grading flow shown in Fig. 4. Impurity removal by reening, aspiration, length and width grading, and specific gravity separations e performed in the oat cleaning section, but the grading by kernel size for lling is performed separately.

Some processors, in addition to performing separate grading for hulling, also move the smaller weed seeds in this separate section as shown, rather than in e oat cleaning section. The size of the oat processing facility frequently termines which approach is taken. In small-capacity plants, it is not feasible to ade the oats by size and then clean each grade separately because the quantity each grade is too small to warrant separate cleaning flows.

Regardless of which method is used, the oats should be graded into at least two zes by length; *plants with very large capacity may grade into three sizes for* lling, as the flow rate of each fraction is sufficiently high to feed the hullers lequately and permit them to be adjusted precisely to suit the size of oats fed to em, thus obtaining maximum hulling effect with minimum tip breakage.

The impact huller shown in Fig. 24 has completely replaced the stone huller; it

is much more efficient, produces a better yield, and requires less horsepower per unit of capacity. The large/medium-size oat hulling and final grading stage and the short (stub) oat hulling system are shown in Fig. 25. The oats enter the center of a high-speed rotor that is fitted with blades or fins that centrifugally throw the oats against a Carborundum ring fixed to the machine housing, where the hulls are detached from the groats by impact and abrasion. The speed of the rotor is adjusted by a variable speed control, according to the type and condition of the oats being processed, to obtain maximum hulling efficiency with minimum breakage of groats and production of fines and chips. Normally, the rotor speed is between 1,400 and 2,200 rpm depending on the size and condition of the oats.

Some processors prefer impact hullers that are fitted with a hard rubber ring, as opposed to a Carborundum ring insert, claiming that the rubber is not as severe and results in less breakage of the groats and less formation of fines. The

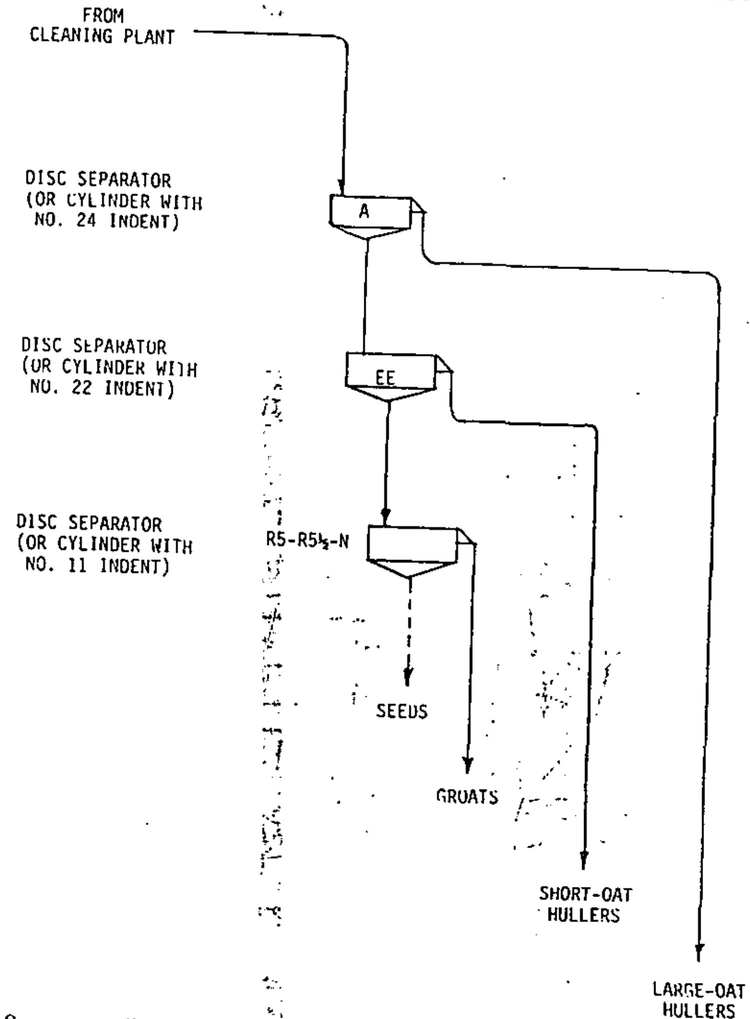


Fig. 23. Separate grading flow for hulling. (Courtesy Carter-Day Co., Minneapolis, MN)

huller produces a mixture of free groats, free hulls, groat chips, fines, and some unhulled oats. A good huller that is well adjusted for the size of oats being fed to it has an efficiency of around 90–95% (i.e., that percentage of the oats is dehulled in one pass through the machine). Badly maintained hullers, or incorrect speed selection according to the size, type, and condition of the oats being processed, can result in an efficiency as low as 55%.

Next comes separation of the mixture of free groats, groat chips, fines, and unhulled oats leaving the huller so that the groats can be isolated for further processing and the unhulled kernels subjected to further hulling. The fines and detached hulls are lifted out of the stream by aspiration; their terminal velocities are sufficiently lower than those of groats and unhulled oats to permit an effective separation on aspirators in which the product mixture falls down an upward-rising air column that lifts out the light particles. Extreme care is required in adjusting air volume and velocity in the air column to avoid excessive loss of small groats and chips with the hull by-product, which has a lower commercial value.

The hulled oats (or groats) are then polished on scourers that subject the groats to a mild surface-abrading action. A scourer consists of a horizontal cylinder, the

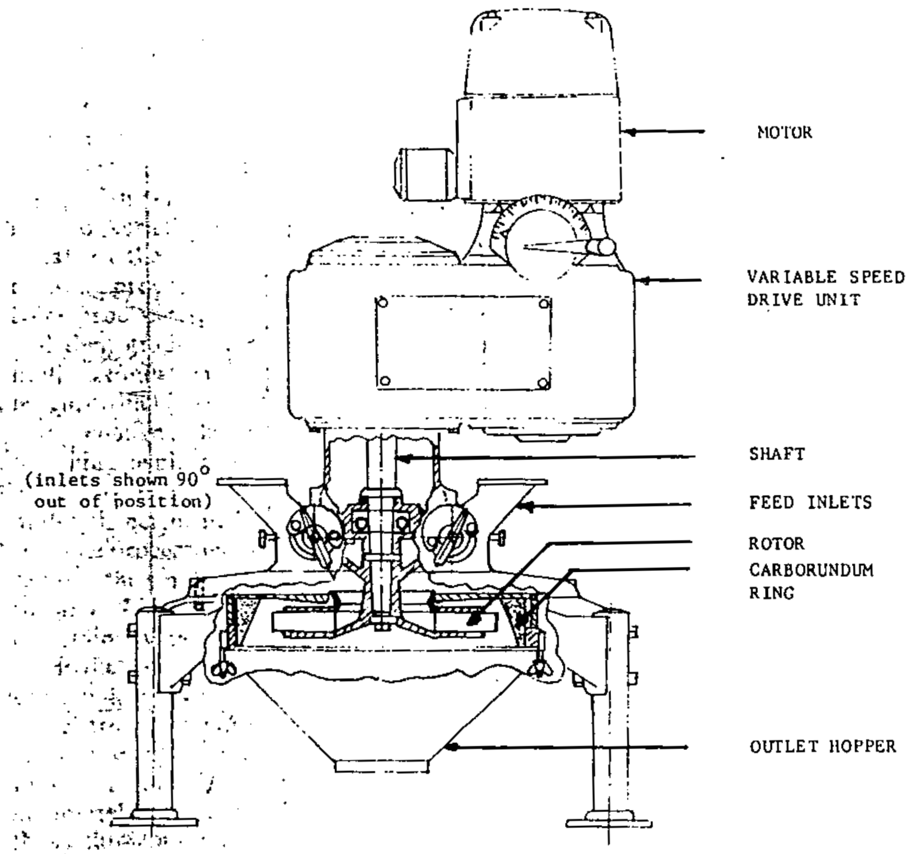


Fig. 24. Schematic of impact huller. (Courtesy Entoleter Inc., New Haven, CT)

inner surface of which is lined with a moderately rough material such as a heavy, intercrimped wire mesh; a horizontal shaft runs through the center of the cylinder, on which are mounted inclined blades that convey the groats against and along the rough cylinder surface. The moderately mild abrading action removes any small pieces of husk still adhering to the groats, and these husk

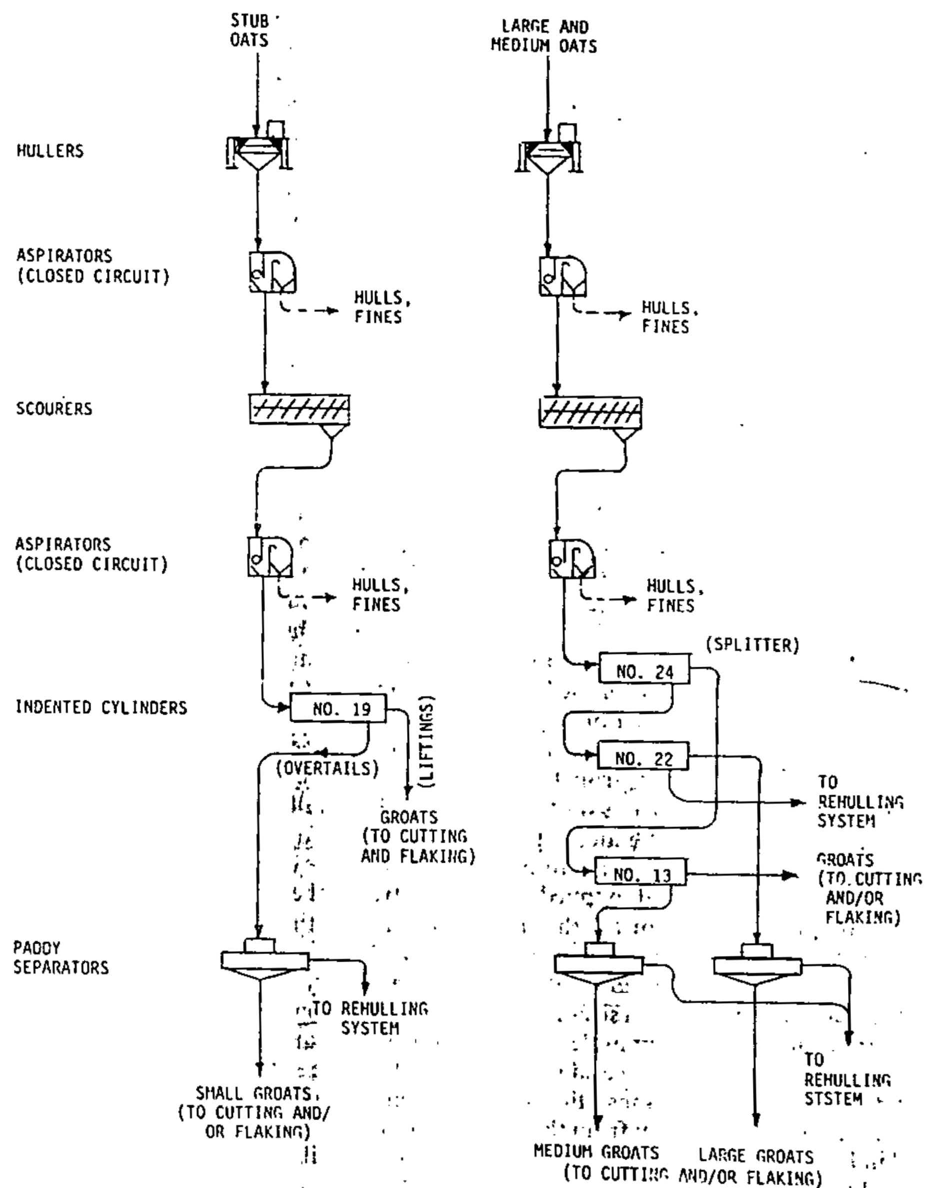


Fig. 25. Hulling and grading flow. (Courtesy Carter-Day Co., Minneapolis, MN)

pieces are then removed by a second aspirator, along with any loose hulls that may have been missed by the initial aspirator.

In the next step, the unhulled oats are separated from the groats. Most of the groats are sufficiently shorter than the unhulled oats to enable a practical separation to be made by disk separators or indented cylinder separators. However, this separation is made less effective by some oats whose groats are as long as the oat and by the huller "clipping" or damaging the tips of some oats that are not hulled in the first pass. The final, difficult separation between groats and "clipped" oats, where little difference in length or specific gravity exists, is made on paddy separators (or gravity separators). The paddy separator is, as previously described, a very sensitive machine that is used in cases where sieving or air separation does not give enough separation; it permits a good separation to be made on products of the same size and shape, based on their slight differences in specific weight, behavior of impact, and floatability. The sensitivity of paddy separators makes them more accurate than gravity separators for the difficult final separation of similar-size groats and unhulled oats. The paddy separator is, however, a rather low-capacity machine, and consequently it is preferable to perform the bulk of the separation, where the size difference between the groats and the unclipped, unhulled oats is not similar, on disk machines or indented cylinder separators and to finish the similar-size separation on paddy separators.

The premium (large and medium-size) oat stream passes from the hullers, aspirators, and scourers to indented cylinder separators fitted with No. 22 and No. 13 indent shells; these separators grade the groats into medium-size and large fractions to facilitate the final separation on the paddy separators (or gravity separators). The initial No. 22 indent cylinder separator splits the stream, lifting out the shorter, medium-size groats mixed with clipped, unhulled oats and overtails the longer, large groats mixed with whole unhulled oats and longer clipped oats. This longer fraction then goes to a second No. 22 indent cylinder separator that overtails the large groats and lifts out the slightly shorter groats mixed with unhulled oats and longer clipped oats, which then flow to a large-fraction paddy separator for the final separation of the groats from the unhulled oats. The groats separated out by the second No. 22 indent cylinder separator and by the paddy separator are ready for further processing on the next stage, whereas the unhulled oats from the paddy separator require further hulling. The shorter, medium-size groats mixed with clipped, unhulled oats lifted out by the initial No. 22 indent cylinder separator go to a third No. 13 indent cylinder separator that lifts out the medium-size groats and overtails the slightly larger groats with the unhulled, clipped oats. This stream then flows to the medium-fraction paddy separator for the final separation of the groats from unhulled, clipped oats that require further hulling action.

Like a conventional gravity separator, a paddy separator works more efficiently when the kernel sizes fed to it are within a small range—hence the need to grade the groats and unhulled oats carefully by size at this stage of the process.

The stub oats are hulled and graded basically in the same manner as the large and medium-size fractions. Following hulling, aspiration, and scouring, the small groats are lifted out from the smaller unhulled oats in this fraction by a No. 19 indent cylinder separator while the cylinder overtails go to a paddy separator for the final separation.

The recovered unhulled oats require a second pass on a huller to detach the

hulls. In smaller mills, these unhulled oats are recycled back to the initial hullers on each respective grade size, and they then pass through the grading system once again. In larger plants, where the quantity of unhulled oats requiring further treatment is sufficiently large to feed hulling and grading equipment, a separate rehulling system is frequently used (see Fig. 26). Since the fraction for rehulling has already been subjected to impact abrasion on the initial hullers, and some of the unhulled oats present have already been clipped, the production of fines and chips tends to be higher on a rehulling system or second pass through the hullers. Consequently, the groats tend to be slightly smaller, and a rehulling system is basically a repeat of the stub-oat hulling and grading system.

The groats separated out in hulling and rehulling systems flow to the cutting and flaking plant for production of rolled oats or to a milling unit to be ground into oat flour, depending on each processor's market requirements.

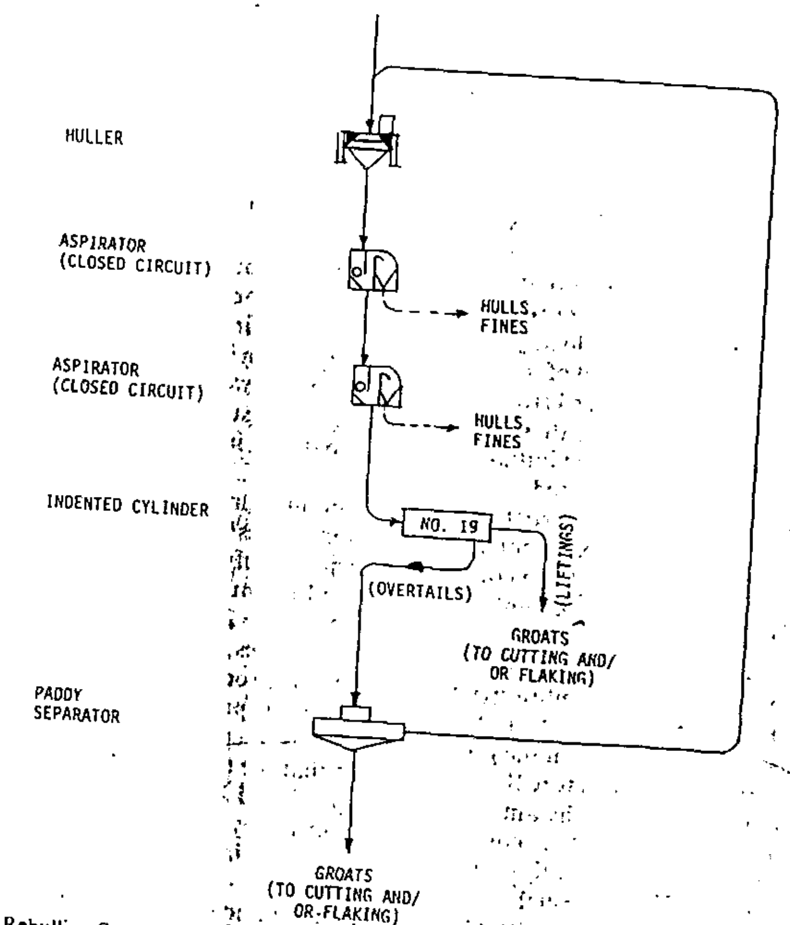


Fig. 26. Rehulling flow. (Courtesy Carter-Day Co., Minneapolis, MN)

VIII. CUTTING AND FLAKING

The groats are now ready for processing into the end products. Broadly speaking, oats for human consumption are sold either as oatmeal or rolled (flaked) oats, or to a lesser extent, as oat flour. Rolled oats constitute the main end product, and, as the name implies, these are produced by flattening the groats between rolls under heavy pressure. To prevent disintegration of the groats and production of fines under heavy pressure, a binding agent must be used to hold the groat particles together. This is achieved by subjecting the groats to steaming immediately ahead of rolling, the heat and moisture serving to bind the flattened groat together. Whole groats produce extremely large flakes that are difficult to handle, store, and package; consequently, the groats are generally cut into uniform pieces, two to four per groat, immediately before steaming. This results, after rolling, in a flake size that is more compatible with packaging requirements and consumer acceptance. Figure 27 illustrates a typical groat-cutting flow.

Groats are cut with rotary granulators, machines consisting of rotating drums perforated with countersunk round holes through which the groats align themselves endwise and fall against stationary knives that are arranged around the bottom and outside of the drum (Fig. 28); there are usually four or six individual drums per machine. The groats are fed into the inside of each drum through chutes at the side of the drums, which are rotating at about 37–40 rpm. The groats fall into the countersunk perforations and come endwise against the series of stationary knives on the outside and bottom of the drums. As the tip of the groat protrudes through the perforation, it is sheared off by the first knife it encounters and, as the groat continues to fall through the perforation, it encounters the next knife as the drum is rotating. This action continues until the entire groat has passed through the perforation and finishes up in two to four pieces. The rotation speed of the drums obviously has an influence on the number of pieces that are produced from a single groat: the slower the speed of rotation, the fewer the groat pieces that will be produced; the faster the speed, the greater the number of pieces. The initial size of the groat also influences the number of pieces of oat groat produced.

The aim is to cut each groat into the minimum number of pieces consistent with the end product requirement because some fines are inevitably produced each time a groat is cut. The condition (sharpness) of the cutting knives has a large influence on the amount of fines: a well-maintained rotary granulator produces about 1.2–1.3% fines, and seldom above 2%; a badly maintained granulator with blunt or incorrectly positioned knives, or with the wrong drum speed for the size and condition of the groats being processed, can produce up to 10% fines, thereby drastically reducing overall process efficiency. Some processors prefer to steam the groats immediately ahead of cutting, rather than after cutting and just before flaking, claiming that the binding action of the heat and moisture reduces the amount of fines produced by the cutting knives. In other operations, groats are conditioned for cutting by adding a small amount of water, rather than steam, about 15–30 min before cutting. The cut groats are then steamed in the conventional way immediately ahead of flaking.

The fines produced by cutting, consisting of oat middlings and flour, are then removed by a shaker screen (or small sifter) fitted with a 22 mesh tin-mill screen (0.032 in. [0.8 mm] opening), although different mesh screens may be used by various processors. The oat middlings and flour are frequently used as a high-quality, high-protein animal feed; again, though, end use depends on each processor's market requirements.

The cut groats are separated from any uncut groats by length-sizing separation on a disk separator using V5-1/2 indent pockets (or a No. 13 indented cylinder separator) (Fig. 27) that lift out the shorter cut groat pieces and reject, or overtail, any longer, uncut oats. The uncut groat fraction is recycled back to the rotary granulator, and some processors prefer to aspirate this recycled fraction to remove any hull pieces before they are returned to the cutters.

The cut groats are now ready for the flaking stage shown in Fig. 29. Conditioning the groats for flaking is accomplished by steaming them with live

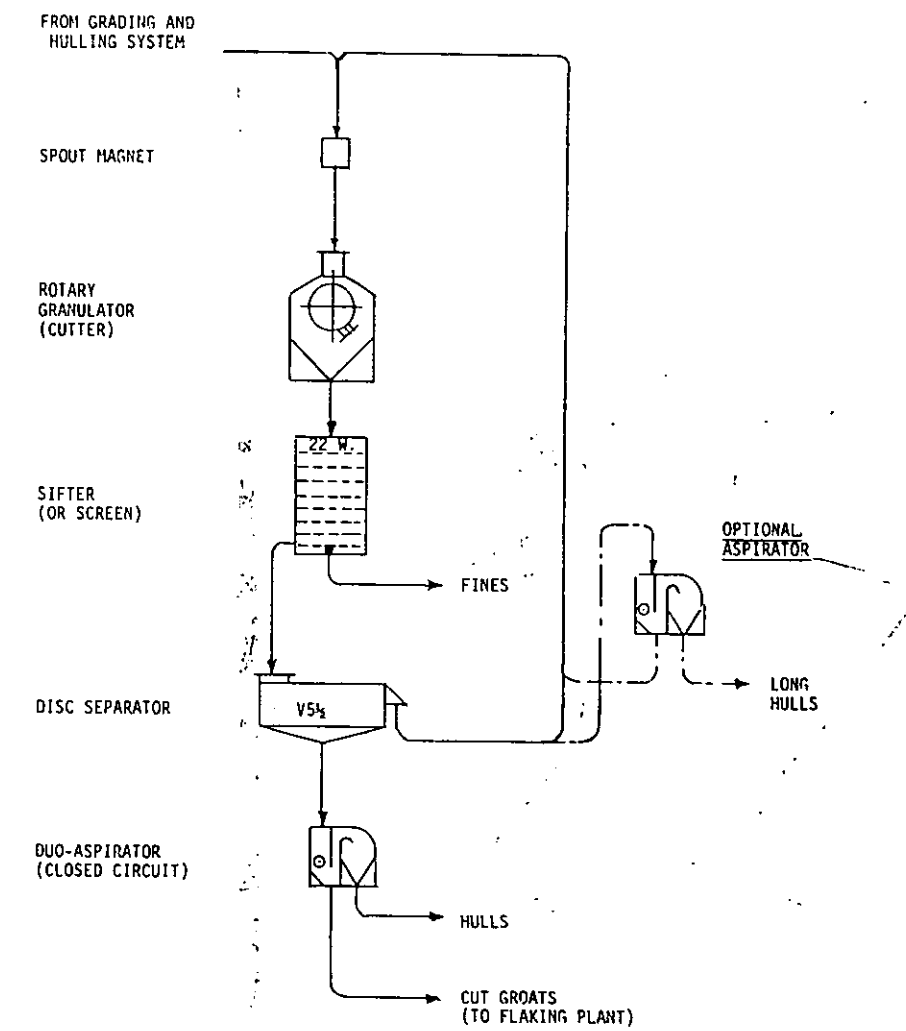


Fig. 27. Groat-cutting flow. (Courtesy Carter-Day Co., Minneapolis, MN)

steam at atmospheric pressure immediately ahead of the flaking rolls. The steaming softens the groats and permits flakes to be formed with a minimum of breakage, and the heat and moisture also complete the inactivation of the enzyme systems that would otherwise cause rancidity and undesirable flavors in the oatmeal.

Although different types of steamers are used, a common one consists of a gradually expanding, cylindrical or rectangular column in which steam nozzles are carefully arranged to ensure that all areas of the slowly descending mass of

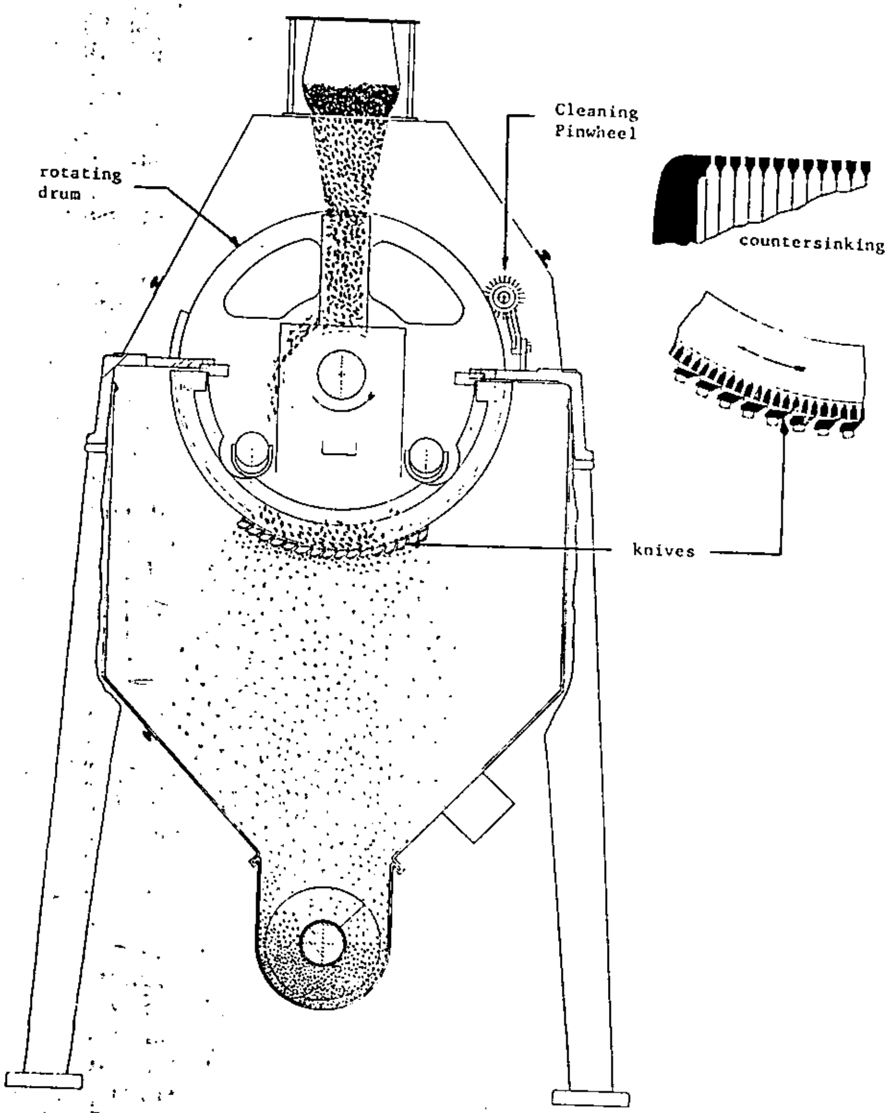


Fig. 28. Schematic of rotary granulator. (Courtesy Kipp-Kelly Ltd., Winnipeg, Manitoba, Canada)

cut groats are subjected to the same amount of steam injection (Fig. 30). Consistent and homogeneous heat and moisture distribution are essential to ensure good quality flakes and yield; too much moisture results in a high percentage of agglomerates, whereas too little produces excessive small flakes and fines. Ideally, the steamer is equipped with automatic controls whereby temperature probes control the amount of steam injected according to predialed and continuously recorded settings. Some processors use horizontal steamers in the form of two- or three-tier screw conveyors with mixing flights and with steam nozzles located in the troughs. This type, however, requires more frequent cleaning to remove the residue that accumulates in the bottom of the trough and

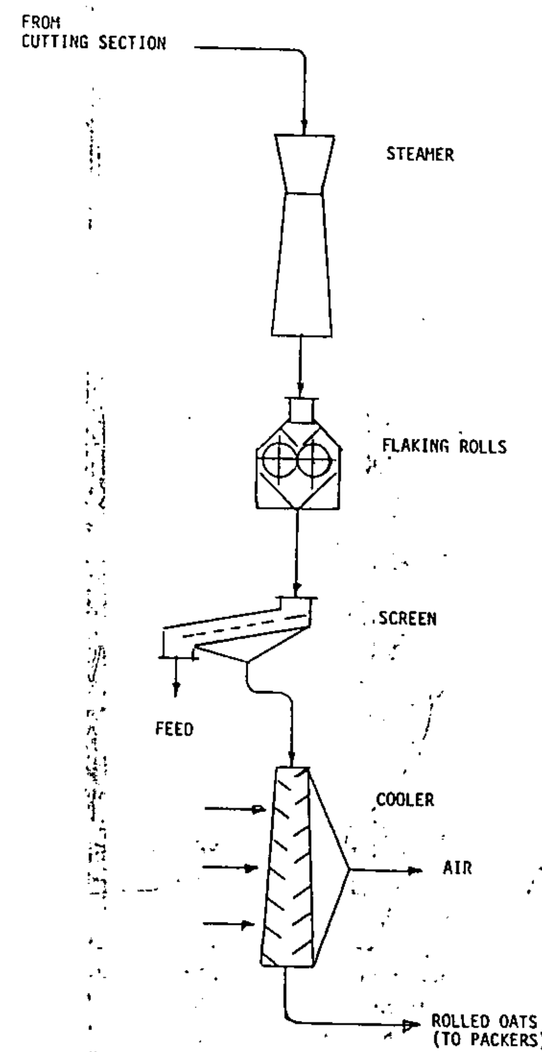


Fig. 29. Oat-flaking flow. (Courtesy Carter-Day Co., Minneapolis, MN)

on the screw flighting; the expanding vertical-column steamer tends to be more self-cleaning because of the continuous downward movement of the cut groat mass.

Retention time in the steamer is about 12–15 min, during which time the cut groat temperature is increased from ambient to 210–220° F (99–104° C). The

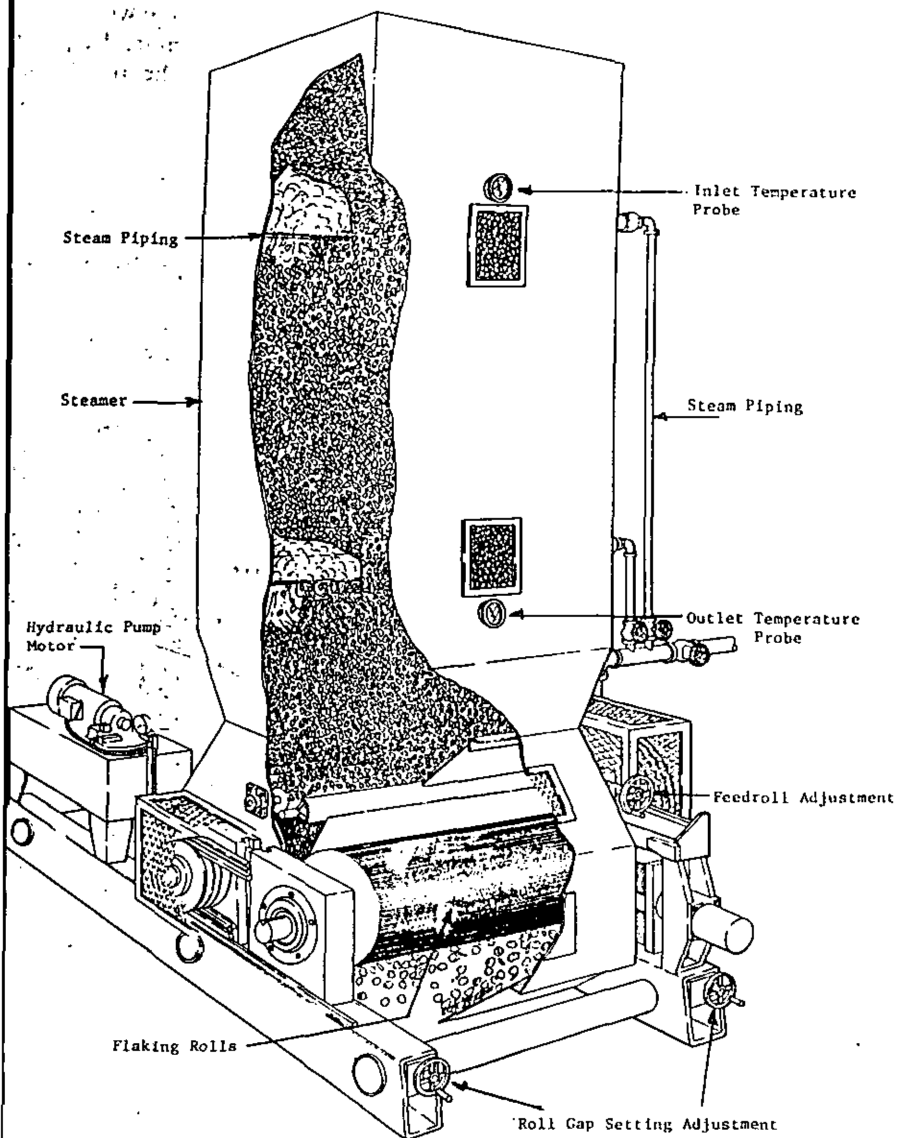


Fig. 30. Schematic of vertical steamer and flaking roll. (Courtesy Roskamp Mfg., Inc., Cedar Falls, IA)

steam increases the groat moisture from about 8–10% when entering to about 10–12% at the steamer outlet.

We noted earlier that some processors prefer to steam the groats before cutting, claiming that the steam conditioning toughens the groats and results in fewer fines during cutting. When this approach is taken, the steamed and cut groats from the rotary granulator pass to the flaking roll.

Regardless of the cutting approach taken, the steamed, cut groats pass directly into the rolls from the steamer. The flaking roll consists of two rigid end frames supporting two cast iron rolls that measure, depending on capacity requirements, from 12 in. diameter × 30 in. long (30.5 × 76.2 cm) to 28 in. diameter × 52 in. long (71.1 × 132.1 cm). A feed gate above the rolls spreads the groats from the steamer along the full length of the roll nip area. The rolls run at zero differential (i.e., the same speed) and rotate at from 250 to 450 rpm, depending on roll diameter and processor preference.

The cut groats are rolled into relatively thin flakes for instant or quick-cooking oatmeal; these flakes have an average thickness of around 0.010–0.015 in. (0.25–0.38 mm). Uncut groats are flaked about 50–75% thicker, or to a thickness of about 0.020–0.025 in. (0.5–0.63 mm) and marketed for regular oatmeal. The moisture content of rolled oats after flaking is about 10–12%. The roll gap distance and nip pressure, which on modern flaking rolls are hydraulically controlled by oil or compressed-air pressure, are adjusted to produce uniform flakes of the thickness desired. The roll gap distance controls the flake thickness and the hydraulic system exerts sufficient pressure to keep the two rolls in the set position.

Following the rolls, the flakes pass directly to a shaker screen (or sifter) where any fines produced in the flaking process are removed. Overcooked pieces, which are generally agglomerates of several flakes, are also scalped off. Finally, the flakes go to a cooler to reduce moisture and temperature to ensure acceptable shelf life. The most common form of cooler is the multilouver type, in which the flakes pass slowly down vertical, rectangular columns through which ambient air is being drawn. Some processors prefer band-type coolers, in which a slow-moving mesh band conveys the flakes from one end of an enclosed housing to the other while ambient air is drawn through the thin, moving bed of flakes.

Flakes enter the cooler, regardless of type, with a moisture content of around 10–12% and a temperature of about 200° F (93° C) and leave the cooling process at 9–11.5% moisture and a temperature of around 110° F (43° C), ready for packing.

The cooled flakes, which represent from 50 to 60% by weight of the oats processed, depending on the quality of the oats and the general efficiency of all steps in the processing system, are next conveyed to the packaging system. Because of the fragile nature of the quick-cooking, thinner flakes in particular, handling and conveying should be kept to a minimum to reduce breakage. Ideally, the flaking system should be located directly above the packaging equipment. Packaging usually includes weighing the contents of each container to safeguard against any inadvertent density variation or change in flake size, which could result in underweight product content. It is also a good idea to have metal detection devices monitoring the packed products before shipment to safeguard against ferrous metal particles becoming mixed in as a result of fragments becoming detached from machines or packaging equipment.

IX. OTHER OAT PRODUCTS AND BY-PRODUCTS

A. Oat Products

Although the major end product is regular rolled oats or quick-cooking (instant) oats for preparation of oatmeal, some processors also manufacture oat flour. Oat flour is primarily used in baby food cereals and ready-to-eat breakfast cereals, providing a good source of high-protein nutrition and flavor compared with flours produced from most cereal grains. It is generally not of the fineness associated with, say, wheat flour, and it has a coarser granulation; the granulation varies depending on the specifications of the end user and the type of product to be manufactured—breakfast cereal, baby food, etc. Oat flour specifications, for example, can range from 100% through 38 wire mesh (0.0198 in. [505 μm] opening) to 75% through 60 wire mesh (0.0127 in. [316 μm] opening).

In the preparation of oat flour, the oats are thoroughly cleaned and hulled as previously described. The hull content must generally be reduced to a very low level, particularly for the preparation of baby foods. The groats are steamed before milling to improve the stability and complete the inactivation of the enzyme system to prevent rancidity. After steaming, the groats are cut or sheared open on a rotary granulator; some processors use a roller mill with grooves or corrugations cut in the rolls for this initial shearing step. Next, the cut groats pass to an impact-type hammer mill where a substantial reduction in particle size takes place, and the ground product is then sifted on a gyratory sifter equipped with wire meshes to correspond to the granulation requirement of the oat flour. Particles that do not pass through the wire mesh are recycled back to the hammer mill in small plants or routed to another, separate hammer mill for further grinding in larger systems. Some processors use a stone burr mill for this final reduction step, reducing the particle size of the cut groats until all the product sifts through the specific wire mesh.

Because of the comparatively high fat content of the groats, it is necessary to have a large volume of exhaust air drawn through impact-type hammer mills to keep the screen perforations open, to prevent fine product from sticking inside the screen and on the beaters, and to prevent heat buildup in the machine.

A few processors produce oat flour on a series of roller mills and sifters. In this type of system, a series of three or four break roller mills gradually reduce the particle size of the groats on grooved or corrugated rolls, the fines produced being sifted out after each grinding passage. Since the groats have a high fat content and have been steamed, only a very gradual reduction of the groats is carried out at each passage to prevent product from sticking in the roll corrugations. From the sifters, particles that are not sufficiently fine pass to roller mills equipped with smooth rolls, which reduce the flour down to the required granulation.

B. By-Products

OAT HULLS

At least 25% of oats is hulls, and consequently a large volume of hulls must be ground and sold. Impact-type hammer mills are used for this purpose. Most hulls

are used as a high-fiber animal feed ingredient or for the production of industrial solvents.

FEED OATS

Light, double, and thin oats that are removed during the cleaning operation are generally used in animal feeds. Although undesirable for milling, these oats are almost equal to normal oats nutritionally for livestock feeding purposes. Typically the feed oats represent about 8–11% of the original oats, although the quantity can vary considerably depending on the quality of the oats purchased and the region of origin.

MIXED GRAINS AND SEEDS

About 2–3% of mixed grains, comprised of corn, wheat, barley, soybeans, sunflower seeds, and weed seeds, are removed during the oat cleaning process. These mixed grains are generally ground on impact hammer mills and sold as an animal feed ingredient.

OAT MIDDLINGS

The fines produced from cutting and flaking normally represent about 3–5% in an efficient plant. Depending on market conditions prevailing for the individual processor, the fines are either sold as a high-grade animal feed supplement or blended into the oat flour milling system.

X. OAT CONVEYING AND EXHAUST SYSTEMS

As these descriptions of the various stages of oat processing suggest, an oat processing plant requires a good deal of both horizontal and vertical conveying of the product from one machine to another, or from one stage to the next. The continuous movement of oats within machines and in conveying equipment creates a considerable amount of dust composed of very small husk fragments and field dirt, which must be carefully controlled for reasons of safety and operator comfort.

For vertical and horizontal conveyance of oats in the intake and cleaning systems, bucket elevators, screw conveyors, or chain conveyors are preferred over positive- or negative-pressure pneumatic conveying lines; oat hulls are most abrasive, and they wear out the pneumatic conveying components (rotary air locks, pipe bends, and cyclone receivers) very quickly, resulting in frequent repair or replacement and high maintenance costs. In addition, pneumatic conveying of oats requires higher power consumption than mechanical conveying equipment, and this represents an ongoing and ever-increasing operating cost. Pneumatic conveying generally takes from 5 to 10 times more power to convey vertically a given weight of oats the height of an average processing facility. Lining the bucket elevator heads with polyurethane, or other abrasion-resistant material, helps to reduce wear and tear.

Gravity spouting between oat cleaning and sizing equipment should be arranged so as to avoid long, straight runs that cause high oat kernel velocities and resultant impact wear on machine inlets, as well as kernel breakage. Self-cleaning checks or "dead" boxes should be used to break long spout runs at changes in spout direction so that oat kernels impinge on other kernels rather than on the spouting. When the flow of oats stops, the check boxes clean themselves out, preventing stagnant pockets that could become a source of infestation.

Areas on or within cleaning and sizing machines that come into contact with the mass of moving or sliding oats should also be protected with such materials as urethane liner plates, abrasion-resistant steel, or ceramic tiles. Machine inlet and discharge chutes and pans underneath sieve screens come into this category of areas subject to rapid wear, and they can benefit from suitable protection. Disk pockets, indented cylinder shells, and slotted sizing shells can be supplied with electroless nickel-plated surfaces to better withstand abrasion from the oat hulls during the separating process.

Adequate protection of conveying equipment and machines, though entailing higher initial costs, drastically reduces long-term repair, replacement, and maintenance costs, and most oat processors consider the expenditure to be a worthwhile investment.

Air contamination can be a major problem in oat cleaning and hulling systems. Small oat-hull sliver fragments and dust escaping to the mill atmosphere can cause considerable operator discomfort in the form of eye and skin irritations. To ensure general plant cleanliness, oat cleaning and conveying equipment must be efficiently exhausted by a well-designed, central system that exhausts air and dust at all points. A central exhaust system consists of an exhaust fan to move the air and create suction, a fabric-filter dust collector, and a network of piping or trunking running from the filter collector to all machines and points to be exhausted. Fabric-filter dust collectors should be selected to operate at liberal air-to-cloth ratios to permit efficient self-cleaning of the fabric filtering tubes and to avoid a buildup of resistance in the system from dust clogging or blinding the tubes. Air-to-cloth ratio is, as the name implies, the ratio of the air volume (cubic feet per minute) entering the filter collector to the fabric cloth area (square feet) inside the filter. Depending on the efficiency of the type of filter collector used, an air-to-cloth ratio of 8:1 (8 ft^3/min per square foot of cloth area), and an absolute maximum of 10:1, is preferred because oat hulls and slivers tend to cling to the filtering cloth media, making self-cleaning of the tubes more difficult than with exhaust systems operating on most other cereal grains.

The cloth tubes inside a fabric filter are usually automatically cleaned by periodic injection of a blast of air from a positive-displacement pump or a high-pressure centrifugal fan onto the inside surface of each tube. The blast of air creates a shock wave down the fabric, loosening the dust that has settled on the outside surface of the tubes as the dust-laden air of the exhaust system passes through the fabric. The loosened dust falls down into a hopper located under the series of cloth tubes and leaves the filter collector through a rotary air lock on the hopper outlet. After a period of time (several months or longer, depending on air-to-cloth ratio and filter efficiency), the filtering media eventually become partially blocked or blinded with dust; the tubes must then be removed and cleaned, or the increased resistance to the air being drawn through the cloth by the exhaust fan drastically reduces the exhaust air on the machinery and conveying equipment, which in turn leads to dust in the plant atmosphere. Fabric filter collectors that enable the cloth tubes to be removed and replaced from the top are desirable because the operator is able to work on the clean-air side of the unit rather than having to enter the dirty side to perform maintenance.

XI. SUMMARY

Previous sections have described the various steps in the oat milling process in general terms. Throughout the industry, each processor has preferred methods and approaches that are suited to particular market requirements; therefore, the process flows and machine details stated are meant to be typical and not necessarily applicable in all cases. Regardless of the individual approaches taken, the overall processing requirements are as described, and variations on them are a means to an end and not another form of oat processing. Whether groats are steamed directly ahead of flaking or directly ahead of groat cutting is a preference based on the experience and requirements of the processor for maximum efficiency. Steaming of the groats remains an essential part of the process regardless of the stage at which it is performed. Similarly, whether oats are graded according to size for hulling during the cleaning process or directly ahead of the hullers is a preference based on results obtained from experience; the fact remains that the oats must be graded for maximum efficiency on the hullers. Each processing stage is an essential part of the overall oat-milling process. Methods may vary, but no step can be eliminated, nor can shortcuts be introduced without sacrificing either quality or efficiency, or both.

Looking to the future, we see no radical changes in the fundamental steps of converting raw oats into rolled oats or oat flour that are followed today. The oats will still have to be cleaned, the hulls removed, and the groats cut, steamed, and rolled or ground. The methods used in achieving each of the processing steps could be changed and improved in future years as technology advances.

The present-day range of oat cleaning equipment, covering screening, grading, sizing, aspiration, and specific-gravity separation functions, is generally efficient, but we expect that refinements and improvements will evolve over the years ahead. The separations may be monitored and controlled by sensors to remove the human adjustment element and to achieve peak operating efficiency at all times. Such factors as the speed, throw, and inclination of screening sieves, the intensity of an aspiration, and the speed of sizing reels in relationship to feed rate may one day be sensor controlled to ensure that no good product is lost with the by-products of less commercial value. Drying of oats may, in the future, be accomplished by infrared heat systems when solar energy has been developed to the point of economic feasibility. Removal of oat hulls may be achieved by ultrasonics with the advancement of sound technology and cheaper natural energy. Small laser light beams may cut the groats for flaking at unimaginable speed and with no fines production, replacing the mechanical method that has been in existence for over a century with little improvement in efficiency.

The roll pressure and speed of flaking rolls may be automatically controlled by sensor and computer to ensure an absolutely consistent flaked end product, regardless of input product variations. As the technological advances over the last 50 years have clearly demonstrated, the limits to advancement in processing technology are far distant; what today seems unlikely or unfeasible may well become a reality tomorrow.

In spite of the potential for technical advancement over the next century, it is necessary to be realistic and to appreciate that oat processing, like other cereal milling processes, is more of an art than a science. The raw material varies in characteristics and quality from one crop year to the next, and the processing requirements are not labor-intensive. Reducing processing costs by replacing manual labor with automated systems is, therefore, difficult to achieve; each advancement in process technology must, of necessity, be financially justifiable in relationship to savings in labor, improved efficiency, or both. With this in mind, we believe that the oat processing technology described in this chapter is likely to change and advance, but only over a long period of time.

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CHAPTER 14

OAT UTILIZATION: PAST, PRESENT, AND FUTURE

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I. INTRODUCTION

Oats have been grown for thousands of years; their primary use, however, has been as a forage crop and a feed grain rather than a food for people. The first reference to human consumption is by Pliny in his *Natural History*. He reported that the Germanic tribes of the first century knew oats well and made "their porridge of nothing else." Despite evidence of early oat consumption, the grain found long-term acceptance only in Ireland and Scotland, where it was used for a variety of porridges. Oatmeal was brought to the New World by Scottish colonists but was not widely accepted as part of the diet. Samuel Johnson said, "Oats—a grain which in England is generally given to horses, but in Scotland supports the people." To which, according to Sir Walter Scott, Lord Elibank is reputed to have replied: "True, but where will you find such horses, where such men?"

During the early 19th century, almost all oatmeal available in this country was imported from Scotland and Canada and sold almost exclusively in pharmacies. Most 19th-century U.S. cookbooks are reported to have either completely omitted recipes for oatmeal or, at best, suggested it as a food for the infirm. *Cookery As It Should Be*, published in 1859, suggested oatmeal for the sickroom and recommended the addition of a huge spoonful of brandy "if the patient could bear it"! Based on this beginning, oats have developed an image as a wholesome and nourishing, hot breakfast cereal. Oats are generally recognized as having the highest protein and lipid content of any cereal grain, and they are also known to be a rich source of dietary fiber (see Chapters 10 and 11).

Three developments in the late 19th century helped establish oatmeal as a staple breakfast item: the large-scale domestic milling of oats; movement of oatmeal from the druggist's shelf to the grocery; and development of packaging, brand names, and promotion. These innovations, pioneered by Ferdinand