2 Materials Preparation Stage I: Opening, Cleaning, and Scouring

2.1 INTRODUCTION

In Chapter 1, it was shown that the yarn production process sequence generally has five stages (see Figure 1.8, in Chapter 1).

Stage I. Opening and cleaning
Stage II. Disentangling and further cleaning
Stage III. Fiber straightening and parallelizing (with short fiber removal and additional cleaning)
Stage IV. Additional fiber straightening, parallelizing, and attenuation
Stage IV. Yarn formation

We may consider the first three stages collectively as material preparation. This chapter is concerned with the process technology of stage I.

In the conversion of baled cotton into finished yarn, the primary purpose of the preparatory processes is to open, clean, and parallelize the fibers and then present the material for spinning. In doing so, these processes convert a three-dimensional bale of compressed, entangled, matted fiber mass into an orderly arrangement of fibers in a one-dimensional continuous strand length. The objective is for the conversion to be achieved with minimal fiber breakage and no fiber entanglement remaining in the strand length. A great deal of attention has been paid to, among other factors, improving machine setting and the operating speeds of component parts so as to attain gentle working of fibers and to avoid fiber breakage.

Fiber properties (such as length, fineness, strength, elongation, frictional characteristics, and the level of impurities present in the fiber mass) are of much importance to machine design and development. Man-made fibers (mmfs) present little problem where impurities are concerned, and, compared with natural fibers, their properties can be more easily modified to meet process requirements. Therefore, the development of most production machines has largely focused on cotton and wool processing; this is particularly so in the area of material preparation. Consequently, most available information on the subject of material preparation mainly concerns cotton and wool fibers, and this is reflected in the present chapter. In certain areas, machinery developments, mainly concerned with component parts, have had to take into account the thermal and frictional characteristics of synthetic fibers. For the conversion of mmfs into semi-worsted yarns, machines have been developed to greatly shorten the production sequence. These topics are also covered in this chapter.

Over many years, machinery developments have been directed at improving yarn quality and reducing production costs by decreasing the number of production stages, reducing maintenance and labor requirements, and increasing production rates. During the last decade, the rapid growth in microelectronics, dedicated software, and information technology has contributed to major advances in automation and production management through machine monitoring and process control. Where relevant, the importance of these developments in the material preparation stages is explained.

2.2 STAGE I: OPENING AND CLEANING

The early stages of material preparation generally involve the removal of impurities from the fiber mass by mechanical or chemical means and the blending of the mass to produce a homogeneous feed to stage II. Several machines are usually arranged in sequence to carry out the cleaning and blending of the fiber mass. The type of machines and the sequence used will depend on the fiber type and grade to be processed. We first concentrate on the rudiments of cleaning and blending, giving examples of machines employed for such tasks, and then present an overview of a typical machine sequence for short-staple, worsted, and woolen systems.

2.2.1 Mechanical Opening and Cleaning

Ideally, the way to remove dirt and trash particles from within a fiber mass is to physically separate the fibers and allow the foreign particles to fall away or to be pulled off the fibers. If fibers have nonparticulate matter on them that needs to be removed (such as grease, to which dirt particles may adhere), this may be removed by scouring the fiber. In situations where there is a high level of particulate impurities, a combination of chemical and mechanical cleaning may be necessary. The chemical used should degrade the physical properties of the impurities without damaging the fiber. In this way, the impurities can be mechanically removed easily.

In an industrial context, fiber mass has to be processed at rates of hundreds of kilograms per hour (kg/h) for manufacturing operations to be economically viable. Cleaning therefore has to be done progressively, since it is not practical to separate hundreds of kilograms per hour of a fiber mass into individual fibers. For example, cotton fiber may be supplied to a manufacturing plant in compacted bales of about 226.8 kg each. The bale dimensions may be typically $1.4 \times 0.53 \times 0.64$ m, and the bale density is 478 kg/m^3 (www.cotton.org). If the individual fibers were, say, 30 mm in length and 1.7 dtex fineness, then there would be around 45 billion fibers in each bale. A typical production rate of an average size plant would be 500 kg/h, which would mean separating nearly 98 billion fibers per hour (i.e., 27 million fibers per second), which is not a practical proposition. However, it is practical to break up the hundreds of kilograms of fiber into a collection of progressively smaller and smaller clumps, called *tufts,* until we obtain sufficiently small tuft sizes that can be then separated into individual fibers at the required production rate. The action of progressively breaking up the fiber mass into smaller clumps is referred to as *opening*.

Definition: Opening is the breaking up of the fiber mass into tufts.

During the process of breaking up the fiber mass into initially large tufts, these large tufts into smaller tufts, and so on, fibers of one part of a tuft bundle slide past fibers of the other part. Light particles of impurities, such as dust, are freed and can be removed by air currents. Larger particles of leaf, seed, dirt, and sand that are lodged between fibers are loosened, and some are sufficiently freed to be removed by beating the tufts against grid bars or perforated plates. We may refer to these actions as *mechanical cleaning* actions or *simply cleaning.*

Definition: Cleaning is the removal of unwanted trash by mechanical means.

Through random variations, fibers from differing parts of the same bale, as well as between bales of the same batch of raw material, will differ in properties, and the difference is more marked for natural fibers than for mmfs. It becomes necessary to mix, as thoroughly as possible, the fiber tufts obtained from opening the various bales to be processed. We therefore speak of *tuft blending* or simply *blending*.

Definition: Tuft blending is the mixing of fibrous tufts from opened bales to produce a homogenous mass for consistent yarn properties.

Tuft blending may take place from the start of removing tufts from the baled fiber mass, but machines purposely designed for blending are incorporated within the sequence of opening and cleaning machines so as to use a suitable tuft size for optimal blending. Often, different grades of a natural fiber or different fiber types are blended for reasons of product economics, product performance, or both. Tuft blending is therefore an essential part of the early processing stage. The reader may reason that the best level of blending would come from mixing individual fibers, but, as we have seen above, the baled fiber mass cannot be "opened up" to the level of individual fibers in the early processing stage. Intimate blending of individual fibers can take place during stages II and III. However, for a good-quality blend to be obtained in stages II and III, it is important that small size tufts of the different fiber types be homogeneously distributed so that, in stage II, the fibers of one type are individualized in close proximity to those of the other fiber types.

Each machine that opens and cleans the fiber mass may be referred to as a *cleaning point,* although some machines do not reduce tuft size but only expel dust, dirt, and trash particles from tufts. Machines are usually placed sequentially in a *cleaning line* so as to progressively intensify the degree of opening and cleaning and to blend the tufts. The fiber tufts are usually transported from one machine to another by airflow through connected ducting. At the end of the cleaning line, 40 to 50% of impurities are removed (largely heavy particles), and the opened material is then fed into the carding process of stage II.

Opening and cleaning machines employ one or more of the following actions:

- The action of opposing spikes, which is principally an opening action
- The action of beater and grid bar, which gives both opening and cleaning
- The action of air currents, which gives only cleaning

The Action of Opposing Spikes

This is effectively an opening action and is usually used at the start of a cleaning line, where the baled fiber mass is initially opened up into large size tufts (e.g., up to 200 g). The machines at the start of opening and cleaning lines may be referred to as *bale openers,* and the following are typical examples.

Figure 2.1 Illustrates the working principle of a *mixing bale opener, bale breaker, or hopper feeder.* This is a traditional way of initially opening the fiber mass. It comprises an extended feed apron (a) onto which layers of the fiber mass are placed, usually manually, a bottom apron (b) within a hopper that assists in transporting the fiber mass to an inclined apron (c) that is covered in spikes and, at the top of this lattice, a spike-covered lattice (d) and a spike stripping or doffer roller (e). The speeds of the component parts can be varied according to production rates. However, the inclined apron (c) operates at a faster surface speed than (b), and both (d) and (e) have higher surface speeds than (c). As illustrated in the diagram, (c) plucks large tufts from the fiber mass fed to it by (b). The gap between (c) and (d) can be set to ensure that the tufts are reduced to a predetermined size by a portion of tuft being removed and returned to the fiber mass on (b), with these portions thereby becoming mixed with new layers of the incoming feed.

Once reduced in size, the tufts are stripped from (c) by (e), the faster speed of (e) giving an additional amount of opening. The components (c) and (d) are termed the *evener apron* and *evener lattice,* as the adjusted gap between the two components enables a reasonably even mass flow of opened tufts at the output. In some machine designs, (d) may be a spike roller, i.e., an evener roller. As described later, the evener apron/evener roller may be used for “weigh-pan blending” of opened tufts.

The mixing bale opener gives a gentle opening action and can be used for the initial opening of man-made fibers, since little cleaning is required, and of wool

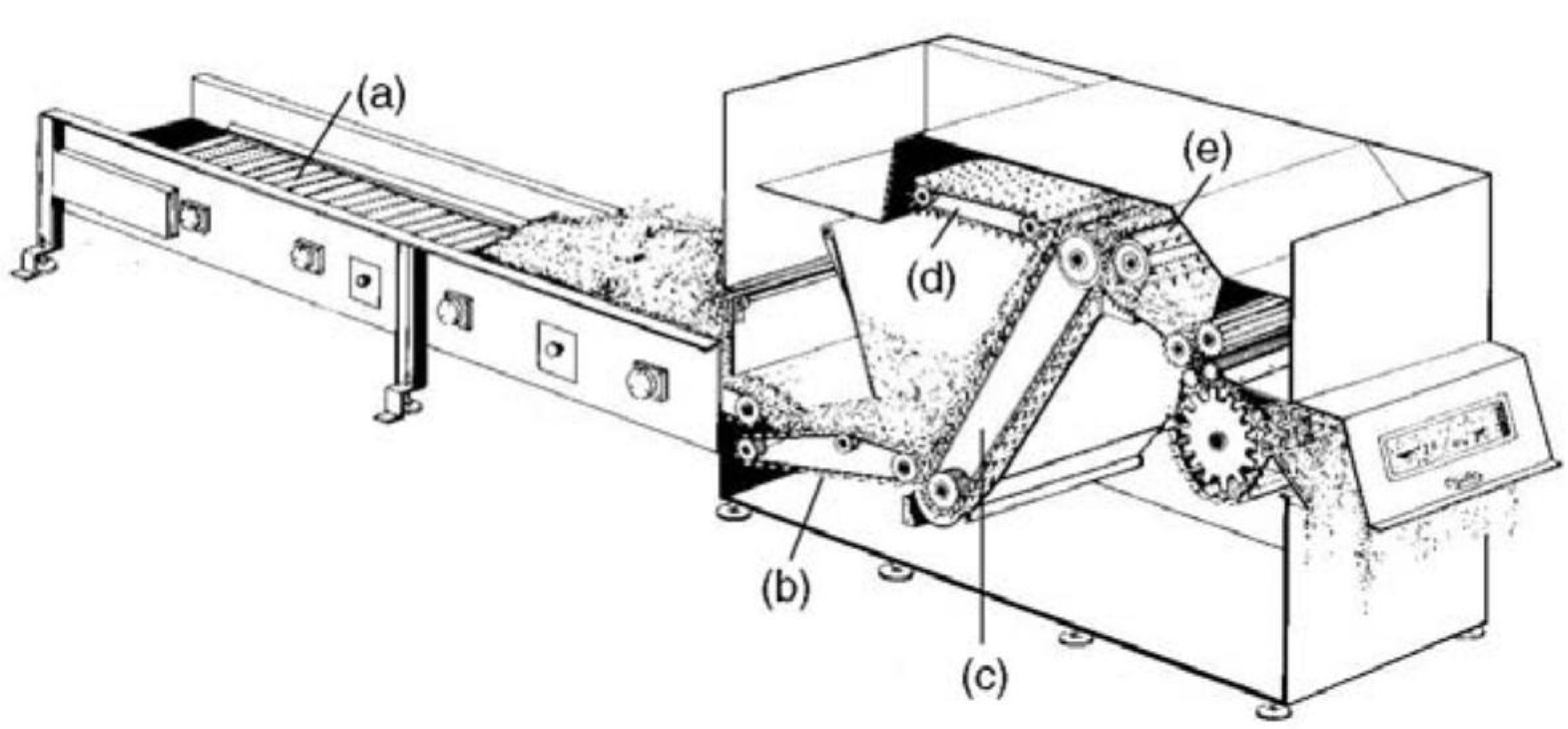


FIGURE 2.1 Mixing bale opener. (Courtesy of Marzoli.)

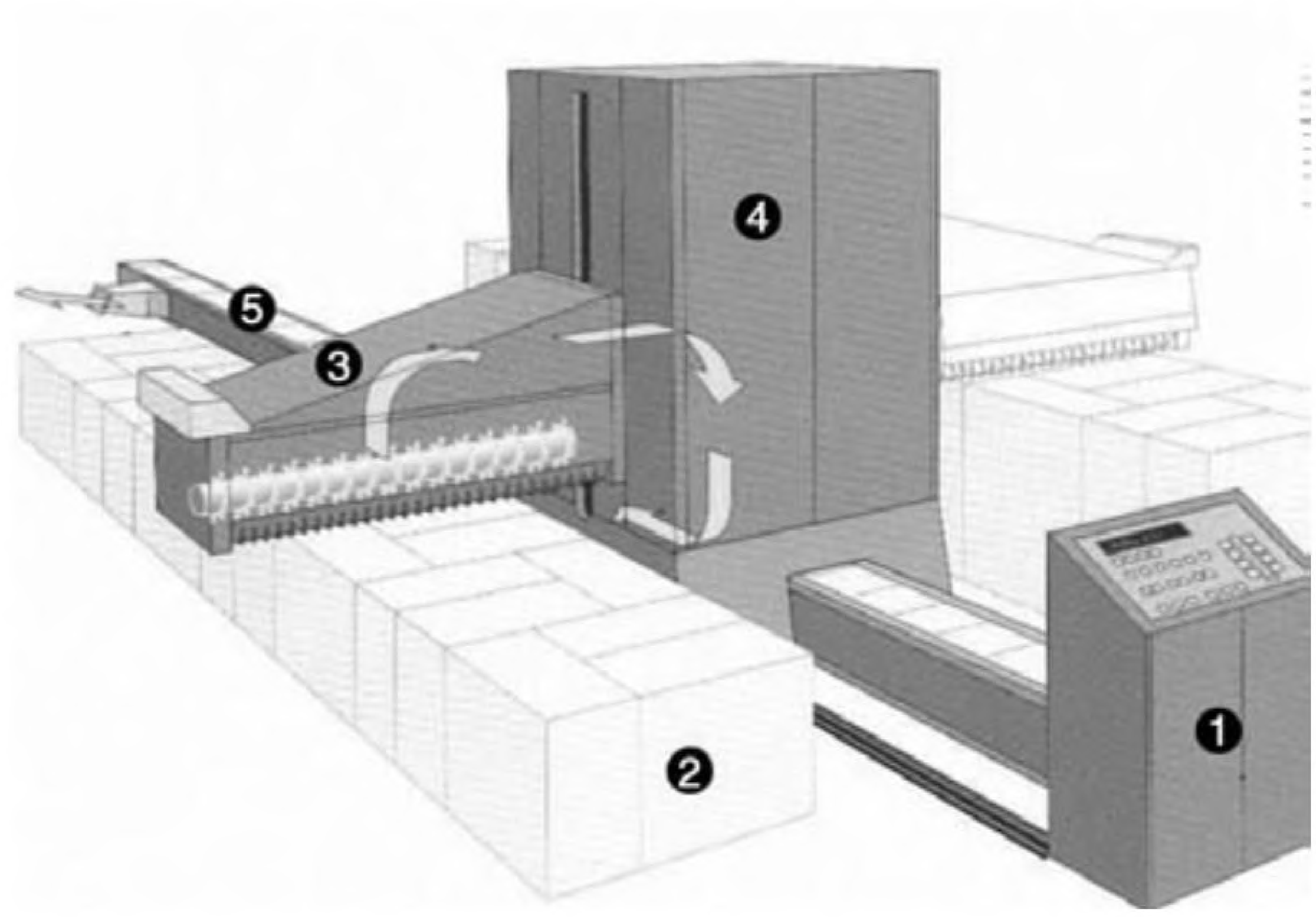
prior to scouring. It can also be used for the feeding of cleaned wools to the carding process. When clean cotton waste is to be recycled and blended with virgin cotton, the mixing bale opener may be also used as a feed for the cotton waste. For short-staple processing, the production rates can be up to 600 kg/h, and up to 3,500 kg/h for longer staples.

The initial opening of bales of virgin cotton and short-staple man-made fibers is commonly performed by machines called a*utomatic bale openers*. Figure 2.2 depicts a typical arrangement. As shown, rotating opening rollers fitted with toothed discs are made to traverse a line of preassembled cotton bales, the toothed discs plucking tufts from each bale as they move from bale to bale. The arrows show the path of tufts transported by airflow. Figure 2.2c illustrates the situation for two opening rollers traversing the bale laydown. Whatever the traverse direction, one roller will always have its working toothed discs opposing the traverse, while the other will be with the direction. Two layers of tufts are plucked in one pass of bale laydown; the opposing toothed discs pluck the first layer, and the discs rotating with the traverse direction penetrate at a lower level from the bale surface to pluck a second layer of tufts. It is claimed that the toothed discs give a gentle opening to prevent, or at least minimize, fiber breakage while producing smaller tuft sizes at higher production rates than the mixing bale opener. For production rates from 400 to 1400 kg/h, tuft sizes fall with the range of 30 to 80 mg and, depending on machine type, bales can be processed at an incline so as to facilitate better tuft blending. Bale laydowns can be up to 180 bales and, as the working head tower can be made to automatically swivel, bales can be assembled on both sides of the traversed path (see Fig. 2.2d). This facility can enable early stage blending of tufts of, for example, a three-component blend as illustrated in Fig. 2.2d.

Automatic bale opening machines have yet to be developed for wool and long-staple man-made fibers. However, the action of opposing spikes has been used for finer opening of long-staple materials. Figure 2.3 shows a *turbo opener,* or *pneumatic opener,* which may be linked to the outlet of a mixing bale opener and utilized to further open the fiber mass. As shown, a rotating cone covered in spikes is fitted to the shaft of a motor drive. The housing matches the profile of the cone, and one section is fitted with rows of spikes or saw-toothed wire. The clearance between the housing and cone varies, becoming progressively narrower from the inlet to the outlet; the latter is tangential to the rotation of the cone. As the cone rotates, the generated airflow sucks the tufts onto the spikes of the cone. With the continued motion of the cones, the tufts make contact with the stationary spikes and are further opened and then ejected with the airflow through the outlet. It is claimed that the turbo opener can process fiber finenesses and lengths of up to 150 dtex and 200 mm, and achieve production rates of 3000 kg/h, depending on fiber type and the degree of opening required.

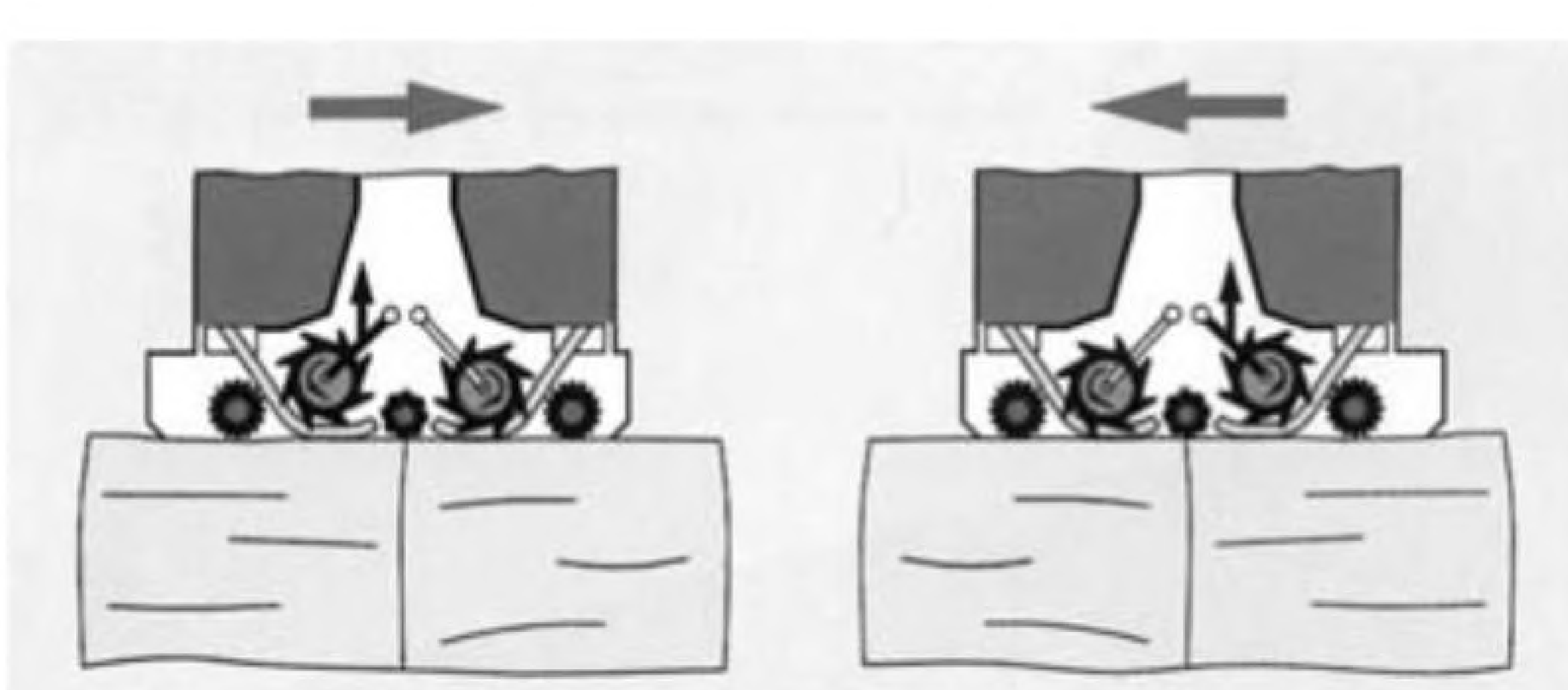
Action of Beater and Grid Bars

This action gives the most effective opening and cleaning of fibrous material. It is therefore utilized in the cleaning stages following the initial opening. Depending on fiber type and the level of impurities, an intermediate opening and cleaning stage may precede a final, intensive opening and cleaning stage, with both stages employ-

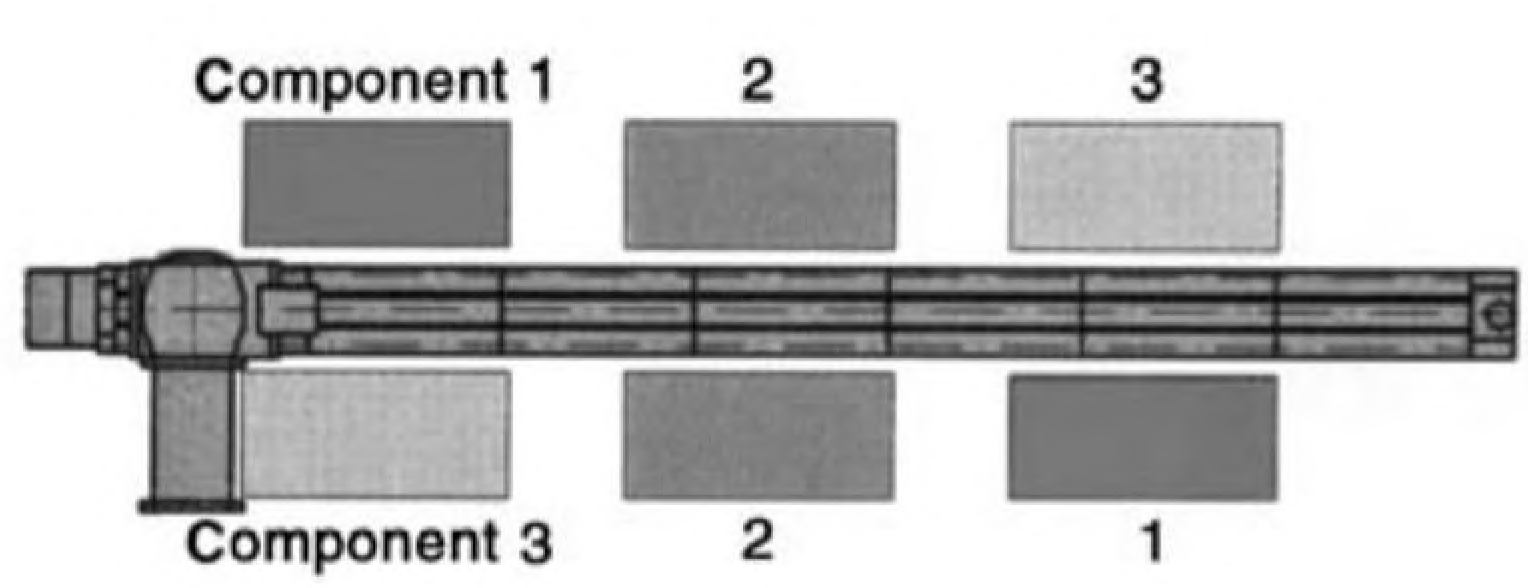


(a) Diagram of automatic bale opener. (1) Control unit, (2) fiber bales, (3), working head with tooth discs, (4) swivel tower, and (5) air duct for material transport. (Courtesy of Rieter Machine Works Ltd.)

(b) Opening of cotton bales. (Courtesy of Marzoli.)

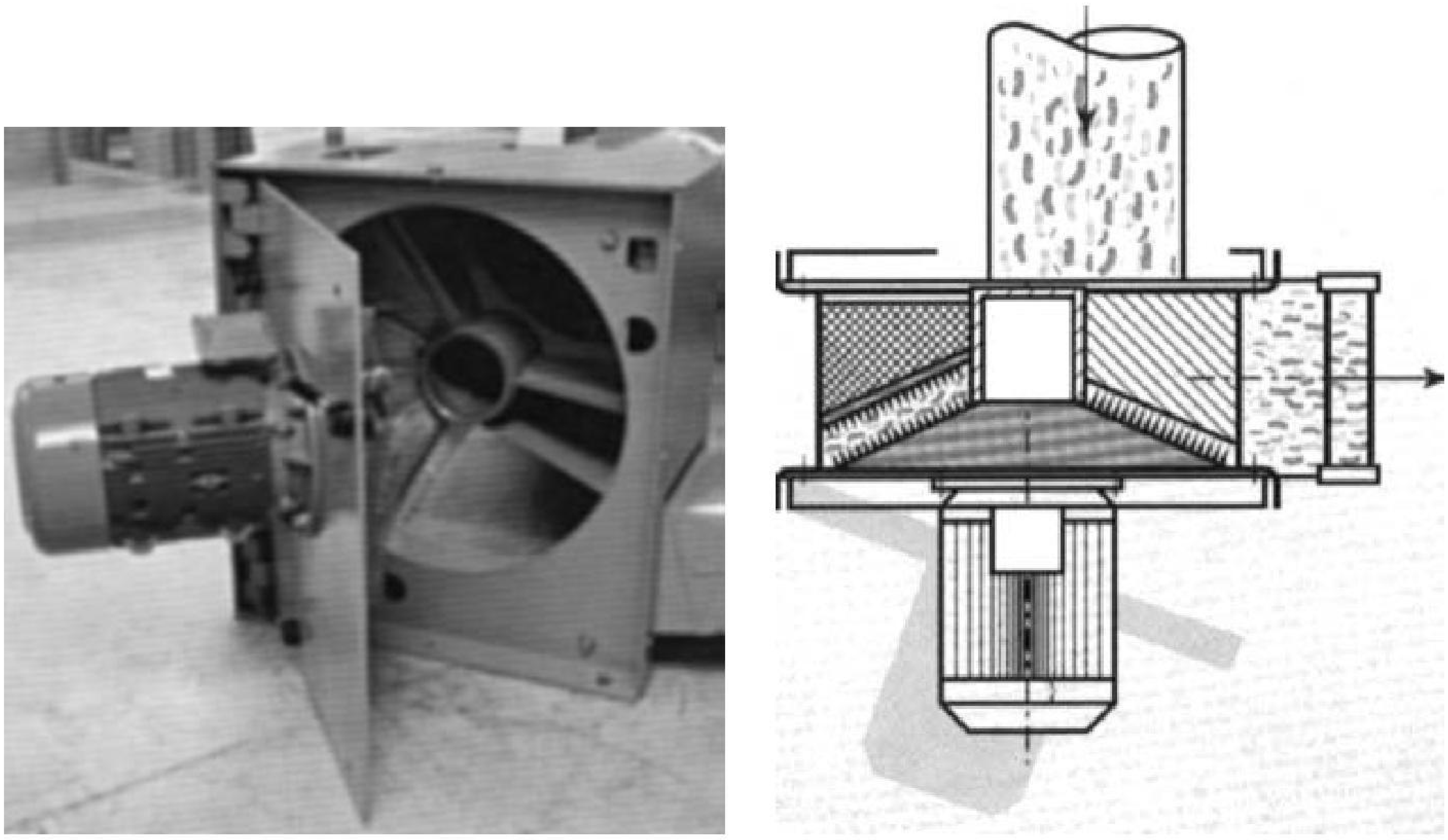


(c) Operation of tooth discs. (Courtesy of Trutzschler GmbH.)



(d) Two-sides laydown. (Courtesy of Trutzschler GmbH.)

FIGURE 2.2 Automatic bale opener.



(Courtesy of Houget Duesberg Bosson.)

FIGURE 2.3 Turbo opener.

ing certain beater and grid bar combinations. There are three different ways of applying the beater and grid bar action. Essentially, these involve striking the fiber mass while it is undergoing one of the following:

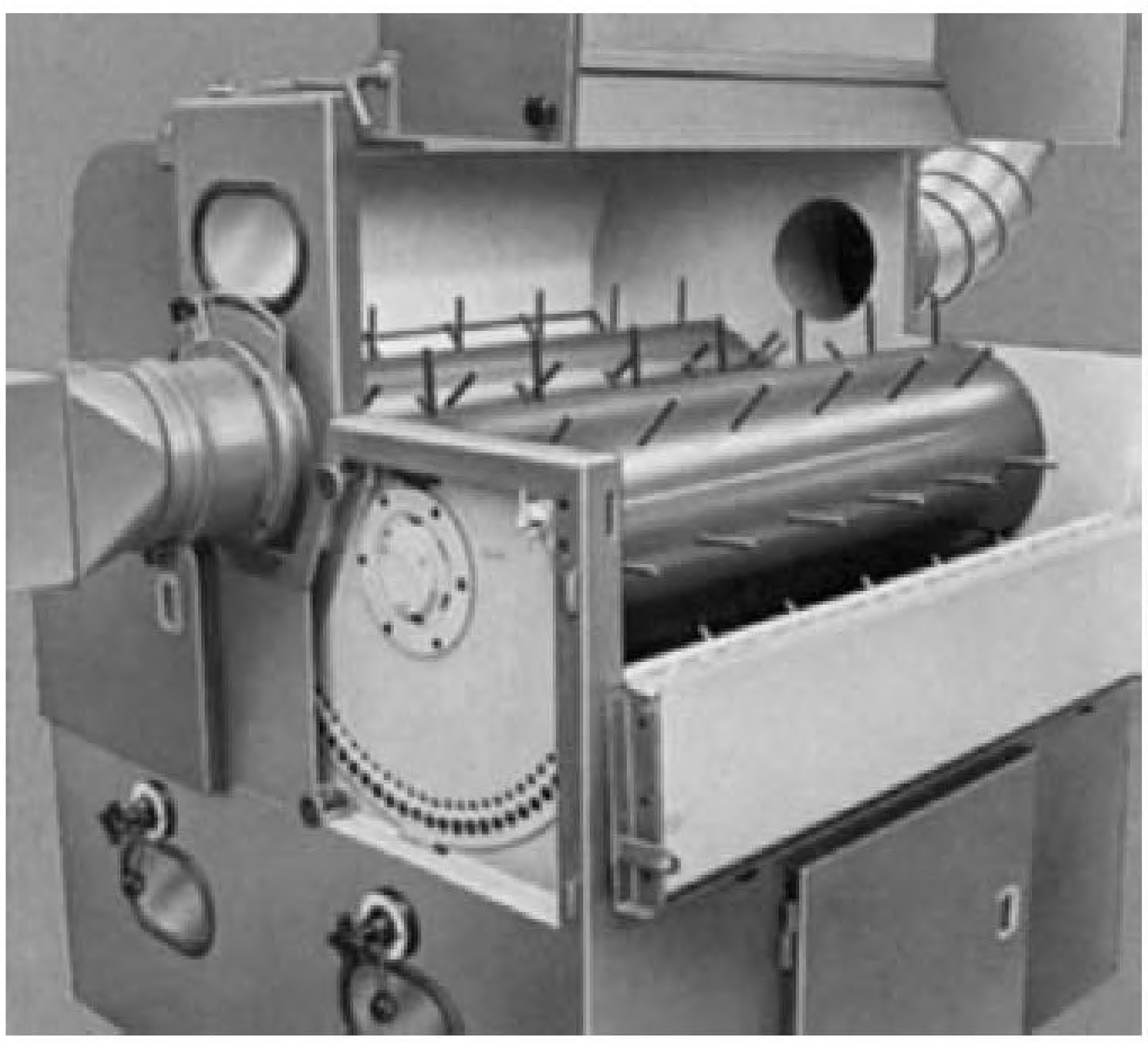
- being transported by airflow
- held by a spike
- held by a pair of feed rollers

With the last two combinations, the beater further opens the material into smaller tuft sizes. In all three, the beater throws the tufts against a set of grid bars. The grid bars are spaced sufficiently close together to prevent tufts from passing between them, but they allow trash particles clinging to the tuft surfaces to be ejected to waste.

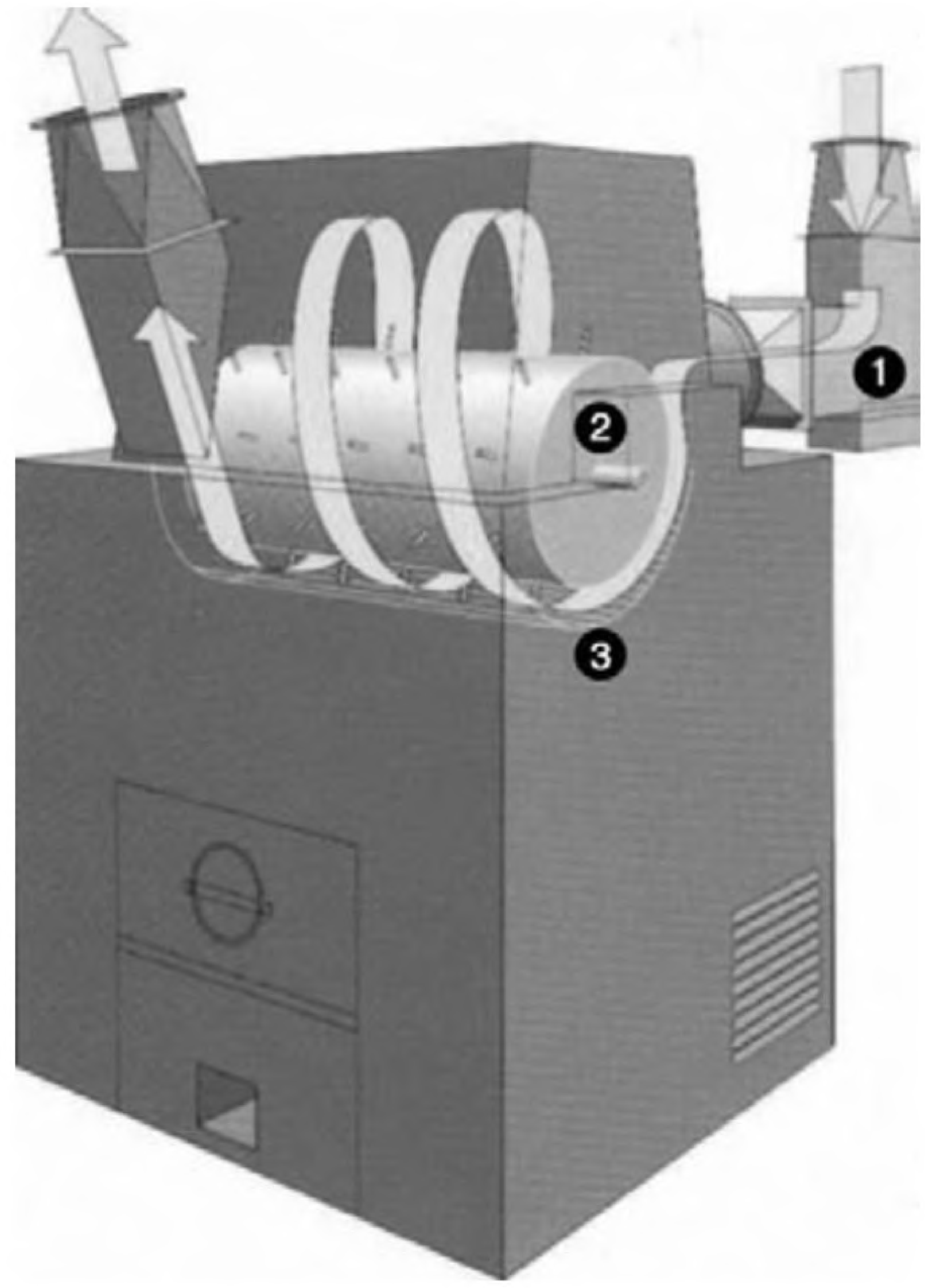
The following machines illustrate typical examples of the application of the beater/grid bar combination.

Beater, Grid Bar, and Airflow

Figure 2.4 illustrates arrangements for ejecting trash particles from tufts carried in airflow. The system comprises one or two rotating cylinders with rods or flexible pins projecting from its surface (i.e., the beater) and a series of grid bars positioned below the beater. The system is used as a first cleaning stage for cotton tufts with high trash content and therefore receives tufts from the automatic bale opener. The two-beater Axi-Flo unit gives added opening as well as cleaning. The outlet for the transporting the airflow is located at a higher position than the inlet so that, on entering the system, small tufts, being lighter, are retained in the airflow and pass through the system with little contact with the beater. This keeps fiber loss to a minimum. Large tufts, which cannot get lost through the grid system, follow a spiral



(a) Axi-Flo cleaner, twin beater with projections. (Courtesy of Trutzschler GmbH.)



(b) Mono cleaner. (1) Inlet, (2) single beater with projections, and (3) grid bars. (Courtesy of Rieter Machine Works Ltd.)

(c) Unifloc cleaner. (1) Single beater, (2) flexible pin projections and grid bars, and (3) trash removal paddle. (Courtesy of Rieter Machine Works Ltd.)

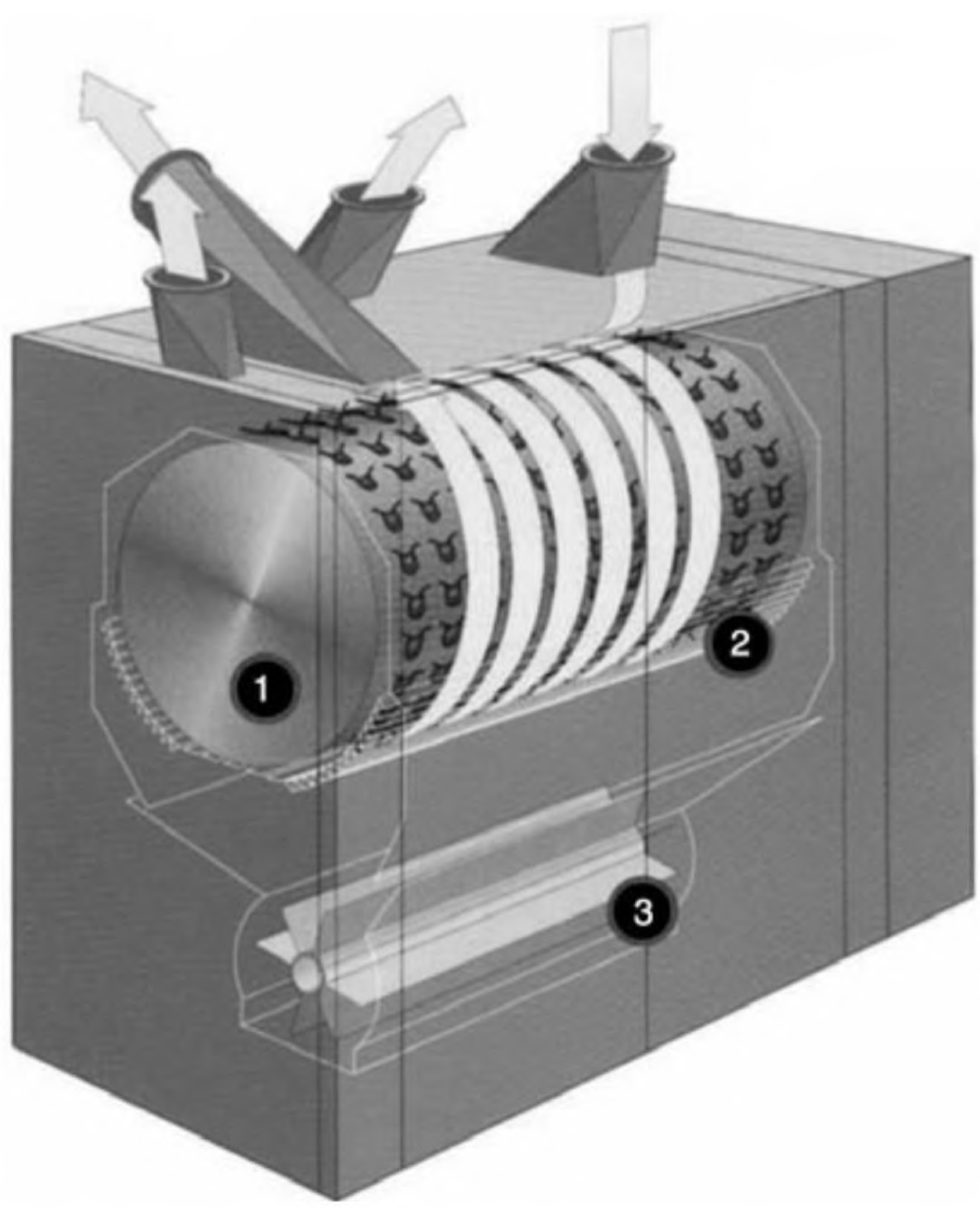


FIGURE 2.4 Beater/grid bar airflow systems.

path around the beater to the outlet and, in doing so, make contact with the projections on the rotating beater surface. The tufts are then flung against the grid bars to eject coarse trash particles. As these large tufts pass between the two beaters, they are further opened by the action of opposing spikes.

The Unifloc single-beater system is a more recent development, and it takes advantage of the small tuft size that can be produced by automatic bale openers. The pin projections from the beater surface are smaller and greater in number, and the objective is to make contact with all tufts. It is claimed that, as well as removing the heavy impurities of sand, dirt, and fine trash, working on small tufts enables the removal of dust particles.

With these systems, curved plates are fitted above the beaters to control the number of spiral passes — usually a minimum of three times. The tufts are accelerated, decelerated, and turned over during each pass. The angle of the grid bars and the space between them can be adjusted so as to optimize the amount of impurities removed and to minimize any removal of fiber. The beater speed range is 400–800 rpm, with a diameter of 750 mm and a working width of 1.6 m; production rates are up to 1200 kg/h. Importantly, trash particles present in the tufts are not crushed. This would increase the number of fine particles, thereby reducing the effectiveness of the system and making subsequent cleaning more difficult.

2.2.2 Striking from a Spike

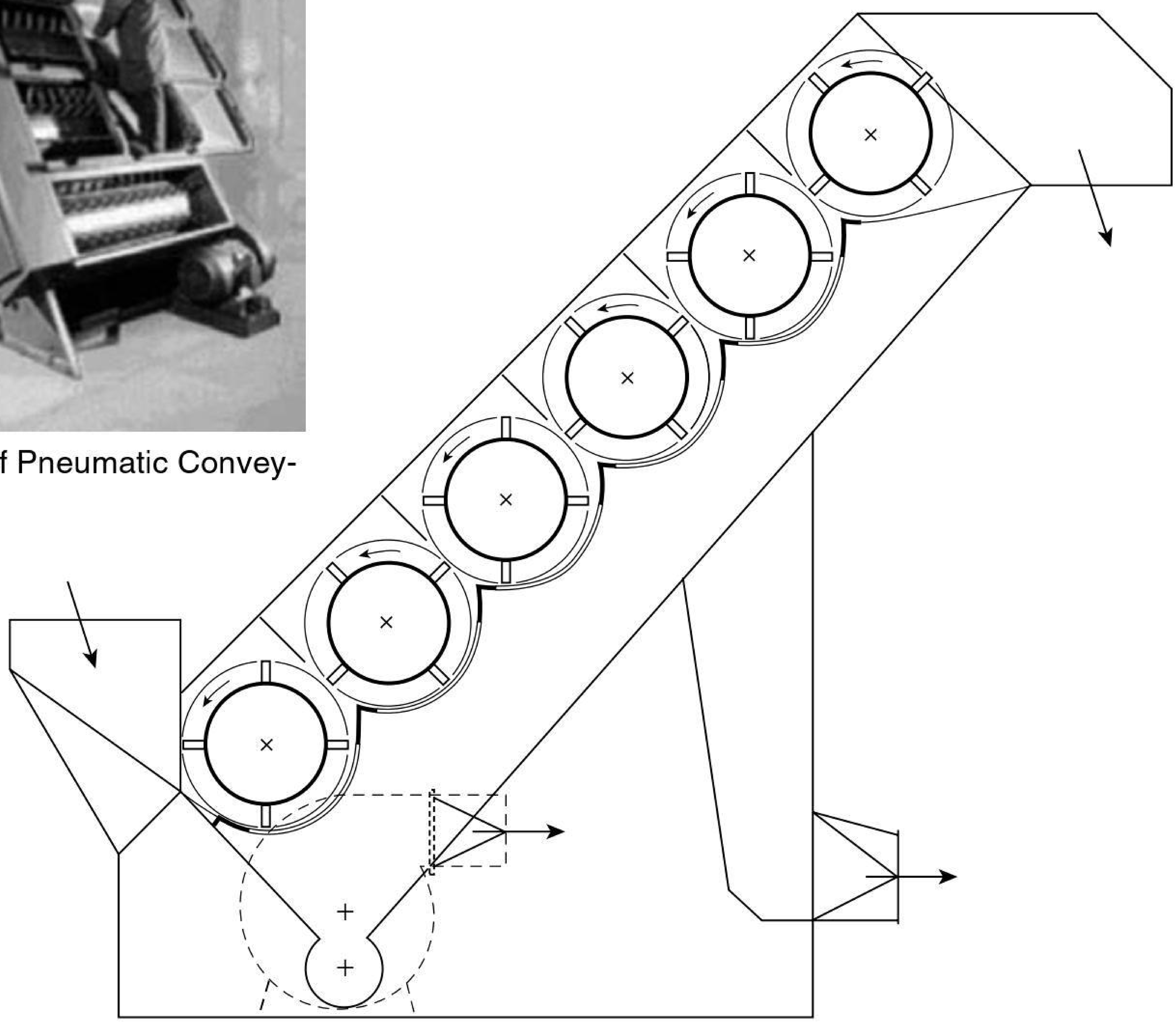
Machines that demonstrate this action are the multiple-beater cleaners. Figure 2.5 shows one example, the inclined multiple-beater system, commonly called a *step cleaner.* Step cleaners perform opening on large tufts by the actions of opposing spikes and with grid bars. Located below each beater is a series of points for removing coarse trash particles. These units are used for the opening and further cleaning of scoured wool prior to carding. The inclined multiple-beater cleaner may have from three to six beaters, depending on the amount of opening required and/or the quantity of impurities to be removed from the material. Step cleaners may also be used in cotton cleaning lines, but, with the move toward mini-tuft size and the use of automatic bale openers, they are no longer part of the specification for a modern cotton spinning plant.

2.2.3 Beater and Feed Roller

Beater-feed roller systems are intensive opening and cleaning units and are usually employed as the last opening stage in a sequence. Figure 2.6 shows two simple arrangements of the beater and feed roller system for short-staple materials. The feed rollers move the fiber tufts toward the pin-covered surface of the rotating beater or roller, which breaks up the tufts into smaller sizes. In the case of cotton, the opening action brings trash particles to the surface of the smaller tufts, and these particles are then ejected by the impact of the tufts on the grid bars. For man-made fibers, the grid bars can be replaced by a stationary pin-covered surface, which would enable a further opening of the tufts.

The beater-feed roller system has developed into a very effective device for cleaning cottons, and, with automatic bale openers being used to produce mini-tufts,

(Courtesy of Pneumatic Conveyors Ltd.)



(Courtesy of Rolando-Beilla.)

FIGURE 2.5 Multiple spike beater rollers with undergrids.

the system has the option of additional beaters to make it a *multi-roller cleaner* for intensive opening of mini-tufts, thereby dispensing with the use of step cleaners for cotton processing. As described in Chapter 1, modern harvesting and ginning of cottons can be severe and, although a larger amount of impurities may be now removed during ginning, intensive ginning causes a greater quantity of fine trash fragments (referred to as *pepper trash*) and neps (i.e., small balls of entangled fibers) to be present in the baled fiber. (See Figure 2.7.)

These particles are not easily removed by the simple impact of large tufts onto grid bars. Intensive opening of mini-tufts releases the fine trash fragments and neps into the boundary air layer of the beater. Replacing the grid bars with a knife-edged slot, and applying suction at the slot, gives effective removal of these particles. Figure 2.8 illustrates a typical knife-edge suction slot device. It can be seen that adjustment of the slot size enables the boundary air layer to expand. The knife edge slows the airflow sufficiently for the trash particles to be ejected by the centrifugal forces acting on them; they are then sucked away. For a set beater speed, adjustment

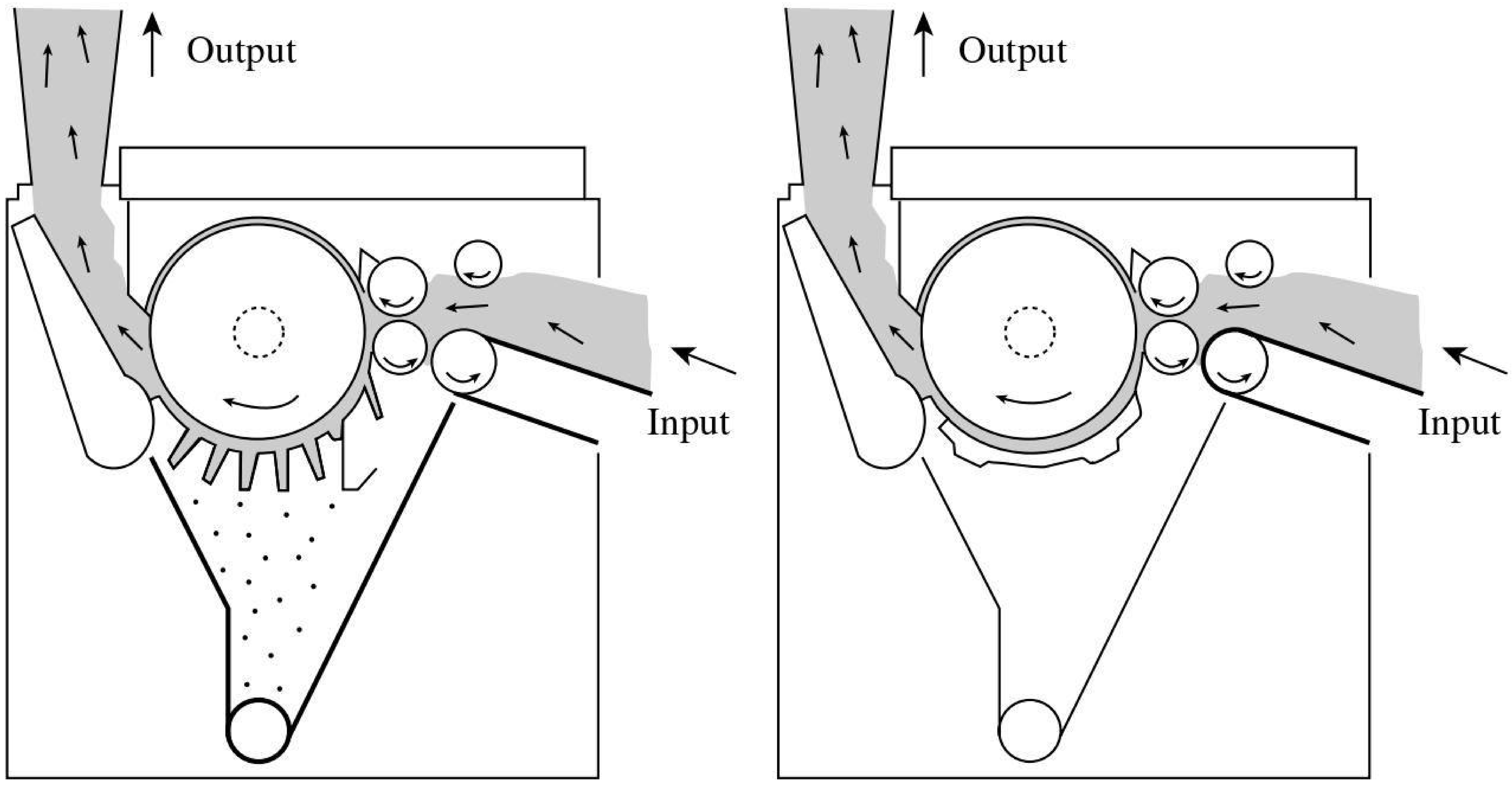


FIGURE 2.6 Beater-feed roller systems. (Courtesy of Crosrol UK Ltd.)

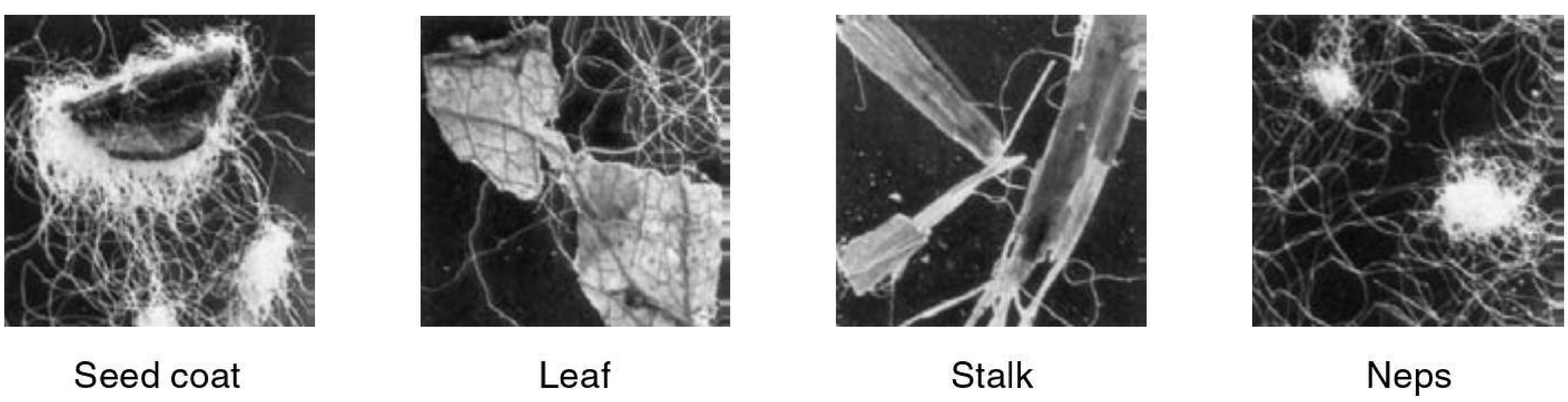


FIGURE 2.7 **(See color insert following page 266.)** Examples of trash fragments and neps found in baled cotton. (Courtesy of Trutzschler GmbH & Co. KG.)

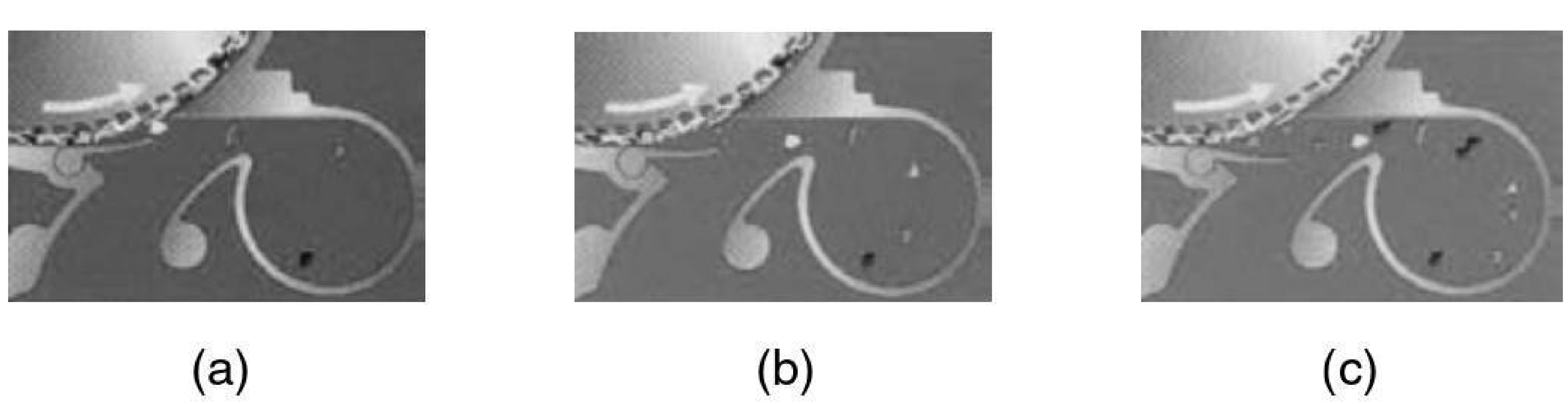


FIGURE 2.8 Knife edge and suction slot for fine particle removal. (Courtesy of Trutzschler GmbH & Co. KG.)

of the slot size controls the degree of cleaning and the amount of fiber removed in the waste. When little cleaning is needed, the slot is opened only slightly (see Figure 2.8a). If the trash level to be removed is high, then the slot is widened accordingly (see Figure 2.8b and c).

Figure 2.9 depicts a multi-roller cleaner having four rollers covered with differing types of working surfaces. Sequentially, the first beater is a spike or needle roll, the second and third are a coarse and medium grade saw-tooth wire roller, and the final roller would have a fine saw-tooth wire clothing. Knife-edged suction slots are positioned around each beater for fine particle extraction. The system may be fitted with two or three beaters or employed as a single beater unit.

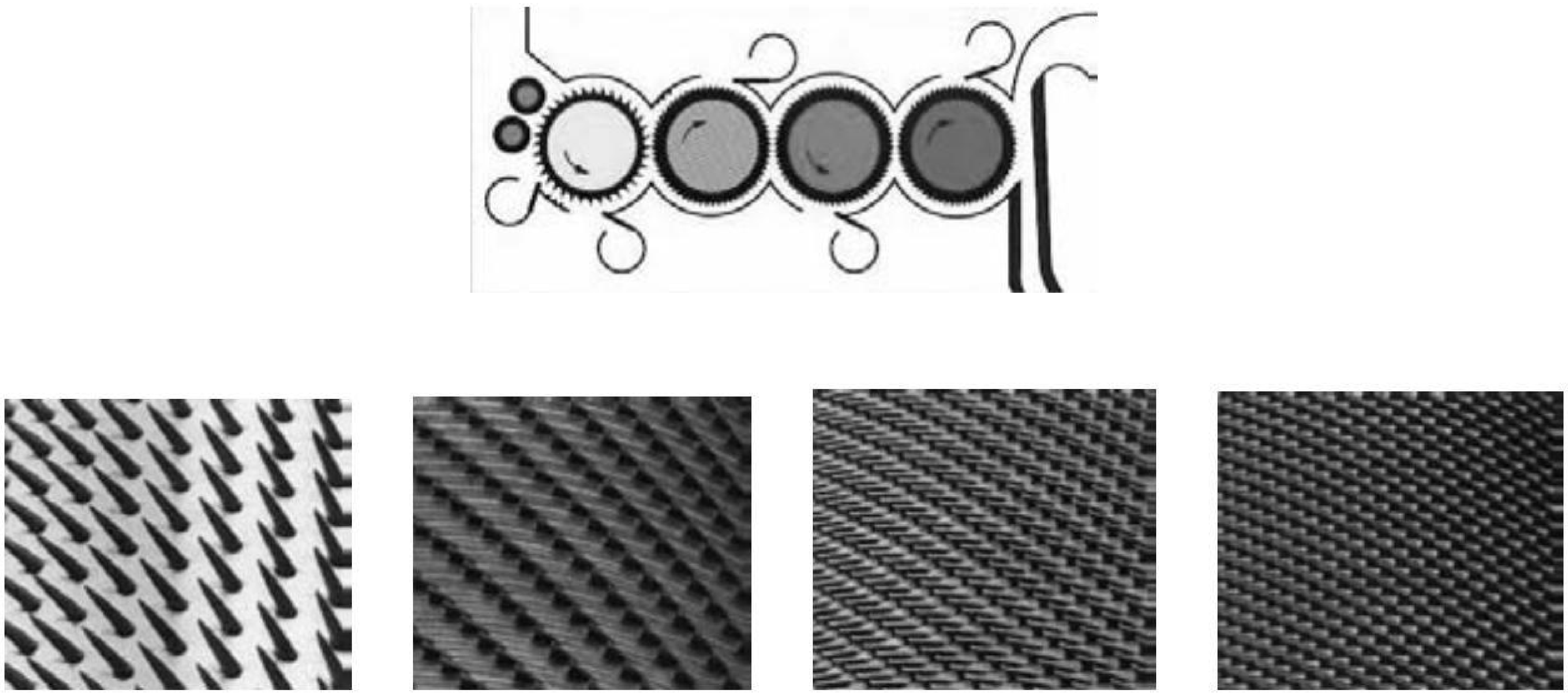


FIGURE 2.9 **(See color insert.)** (Top): Multi-roller cleaner. (Left to right) needle beater followed by coarse, medium, and fine saw-tooth beaters. (Courtesy of Trutzschler GmbH & Co. KG.)

The Picker and Fearnought Openers (Figure 2.10) are typical beater-feed roller systems used for producing mini-tufts in the opening of wool and other fibers of similar length and fineness. Whereas the Picker operates along the lines of a single beater unit, the Fearnought is more complex and functions similar to a carding system, which is described in Chapter 3.

2.2.4 Use of Air Currents

There are two basic ways in which cleaning can be achieved with the use of air currents.

1. Removal of trash particles by an imbalance of centrifugal and aerodynamic forces on the particles
2. The use of a perforated screen to separate tufts from a dust-laden airflow

The knife-edged suction slot is a basic method of using an imbalance of centrifugal and aerodynamic forces, and Figure 2.8 in effect shows one example of its application. Figure 2.11 shows a more commonly used approach. Here (Figure 2.11a), a section of ducting is made with a bend of an almost 120° angle and an adjustable slot located at the bend. The tufts are pulled through the ducting by air suction, the speed of incoming air at the slot being greater than the flow transporting the fiber tufts at the inlet section of the ducting. The transporting airflow may contain trash particles that escaped removal in a prior cleaning stage.

If the forces on the tufts and the trash particles entering the inlet are resolved into their x and y components as shown, then it is clear that, with the x component being larger, the resultant paths are toward the slot. At the slot, forces from two other influences come into play: that because of the faster intake of air at the slot and centrifugal forces due to the action of moving around the bend. The larger surface area and lower relative density of the tufts mean that forces due to the intake

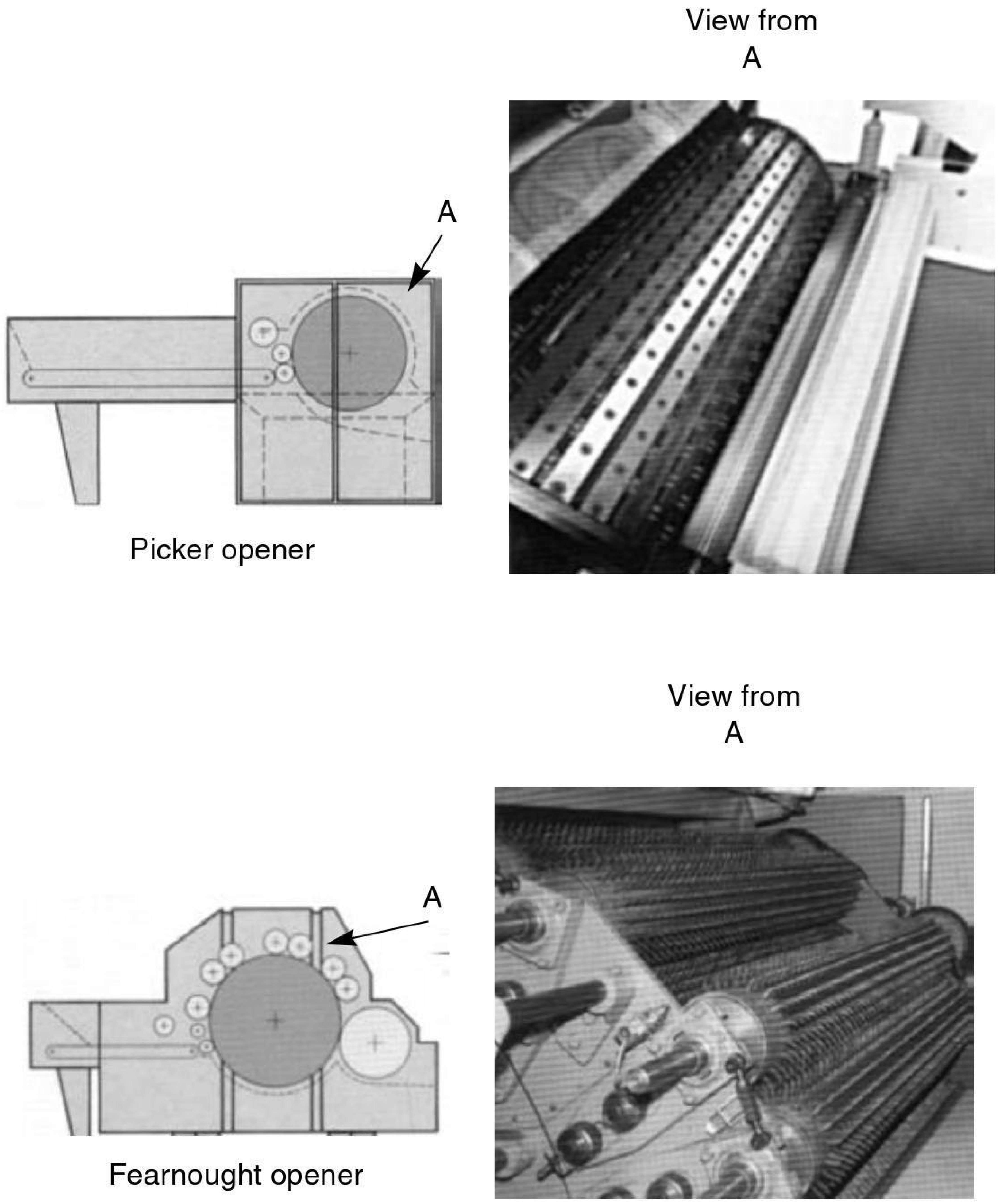


FIGURE 2.10 Picker and Fearnought openers. (Courtesy of Rolands Macchine Tessili.)

of air at the slot are greater than the centrifugal forces acting on the tufts, and the tufts are therefore retained in the airflow. The converse is true for the trash particles, and they are ejected from the trucking. Figure 2.11b illustrates the use of this principle to aid particle separation.

To remove dust particles in transporting airflow, a perforated surface may be used to separate the tufts from the dust-laden air. Figure 2.12a illustrates the use of a slowly rotating perforated drum as one example, often referred to as a *condenser drum, cage condenser,* or *dust cage.* The airflow in which the tufts are conveyed is generated by a fan connected by ducting to the interior of the cage. As shown, the tufts are pulled onto the outer surface of the drum, the holes being sufficiently small to prevent fiber loss, while the dust-laden air flows through the holes of the drum for the dust to be collected as waste. To remove the tufts attached to the slowly rotating drum, the suction is blanked off by a half-cylinder screen, which is positioned where the tufts are required to leave the drum. Condenser drums are positioned at the inlet to a hopper either before or after an opening stage (see Figure 2.12b).

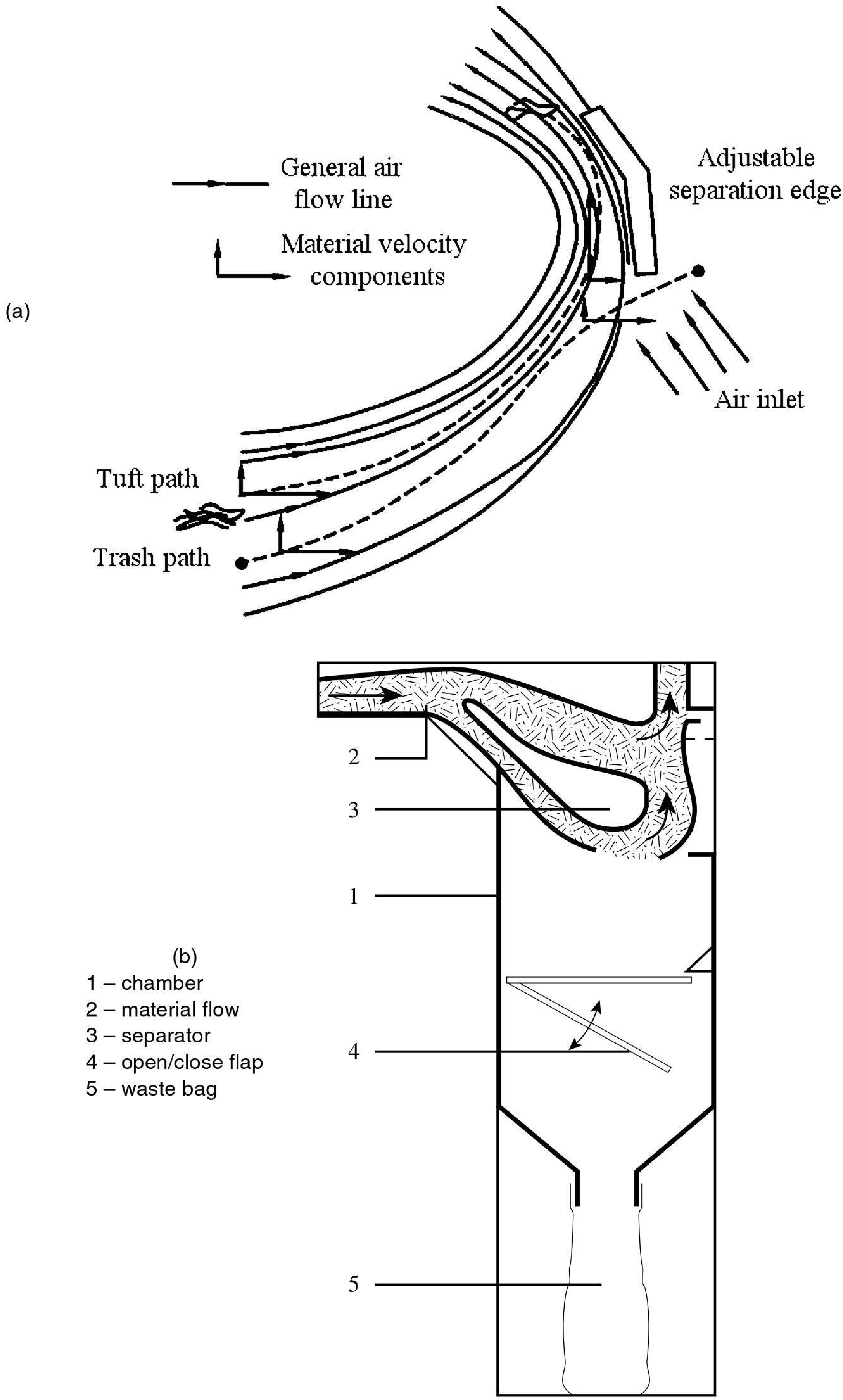


FIGURE 2.11 Heavy particle separator. (Courtesy of Trutzschler GmbH & Co. KG.)

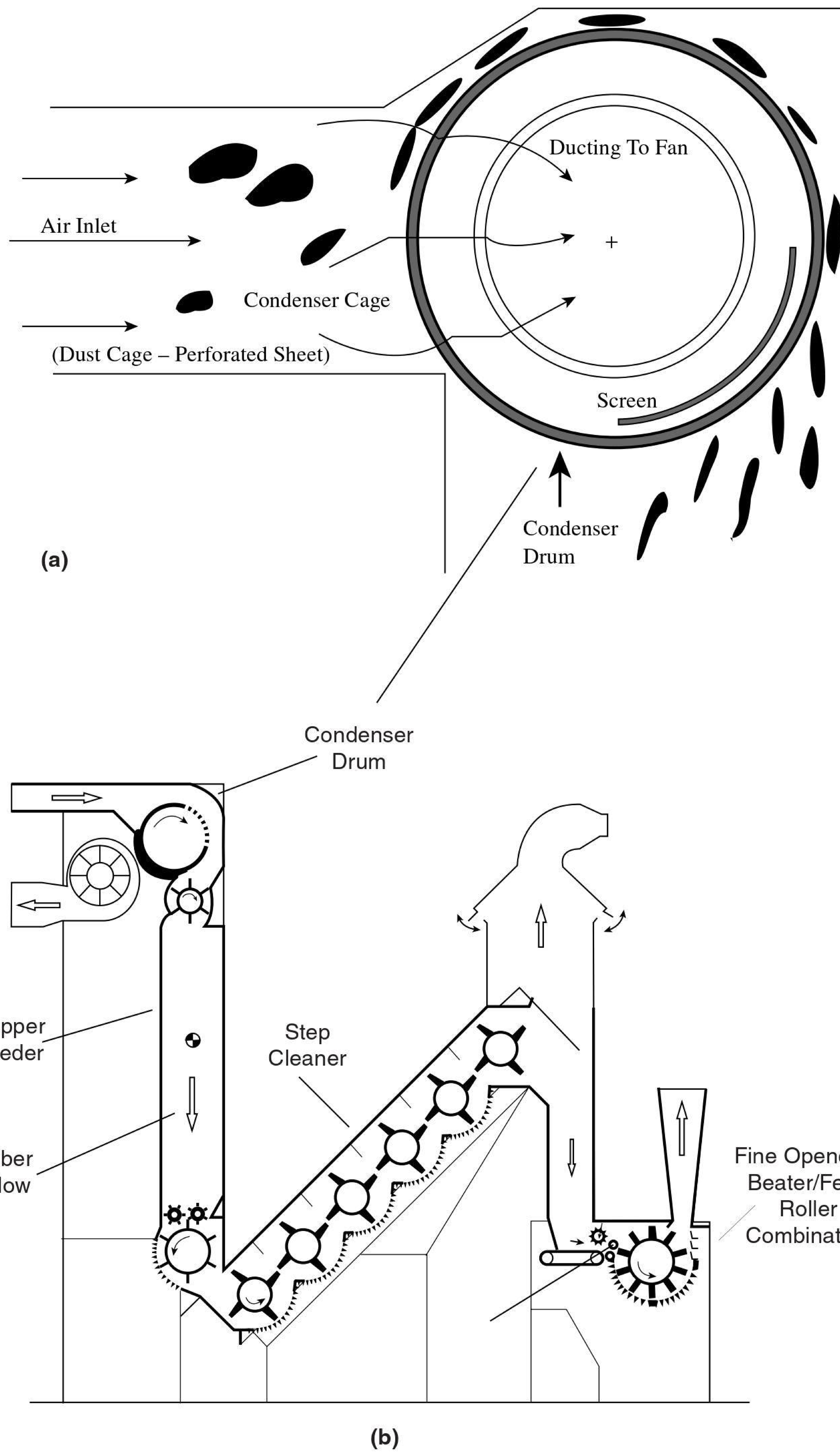


FIGURE 2.12 Condenser Drum for Removal of Dust Particles. (Courtesy of Trutzschler GmbH & Co. KG.)

Clearly, the larger the area of the perforated surface, the more effective the dust removal will be. Figure 2.13 depicts several of the newer developments, which are self-explanatory.

2.2.5 Estimation of the Effectiveness of Opening and Cleaning Systems

2.2.5.1 Intensity of Opening

To assess the opening action of a beater, we refer to its *intensity of opening*. This can be defined as the amount of fibrous mass in milligrams per one striker of a beater for a preset production rate and beater speed.[1] Thus,

$$I = \frac{P \times 10^6}{60 \times n_b \times N} \tag{2.1}$$

where I = intensity of opening (mg)
P = production rate (kg/h)
n_b = beater speed (rpm)
N = number of strikers

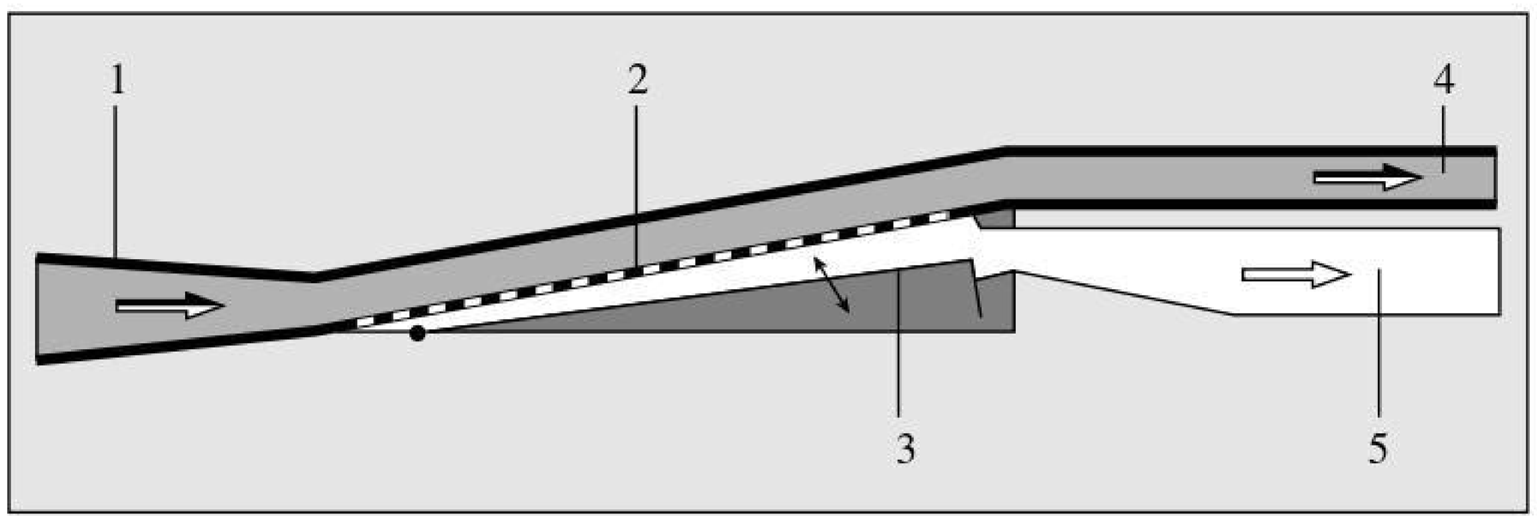
Table 2.1 gives examples of I values for commonly used beaters. The intensity of opening is an estimate of the tuft size produced by a given beater. From the I value, we can get an approximation of the number of fibers, n_f, constituting a tuft produced by a given beater.

TABLE 2.1
Examples of *I* Values of Beaters

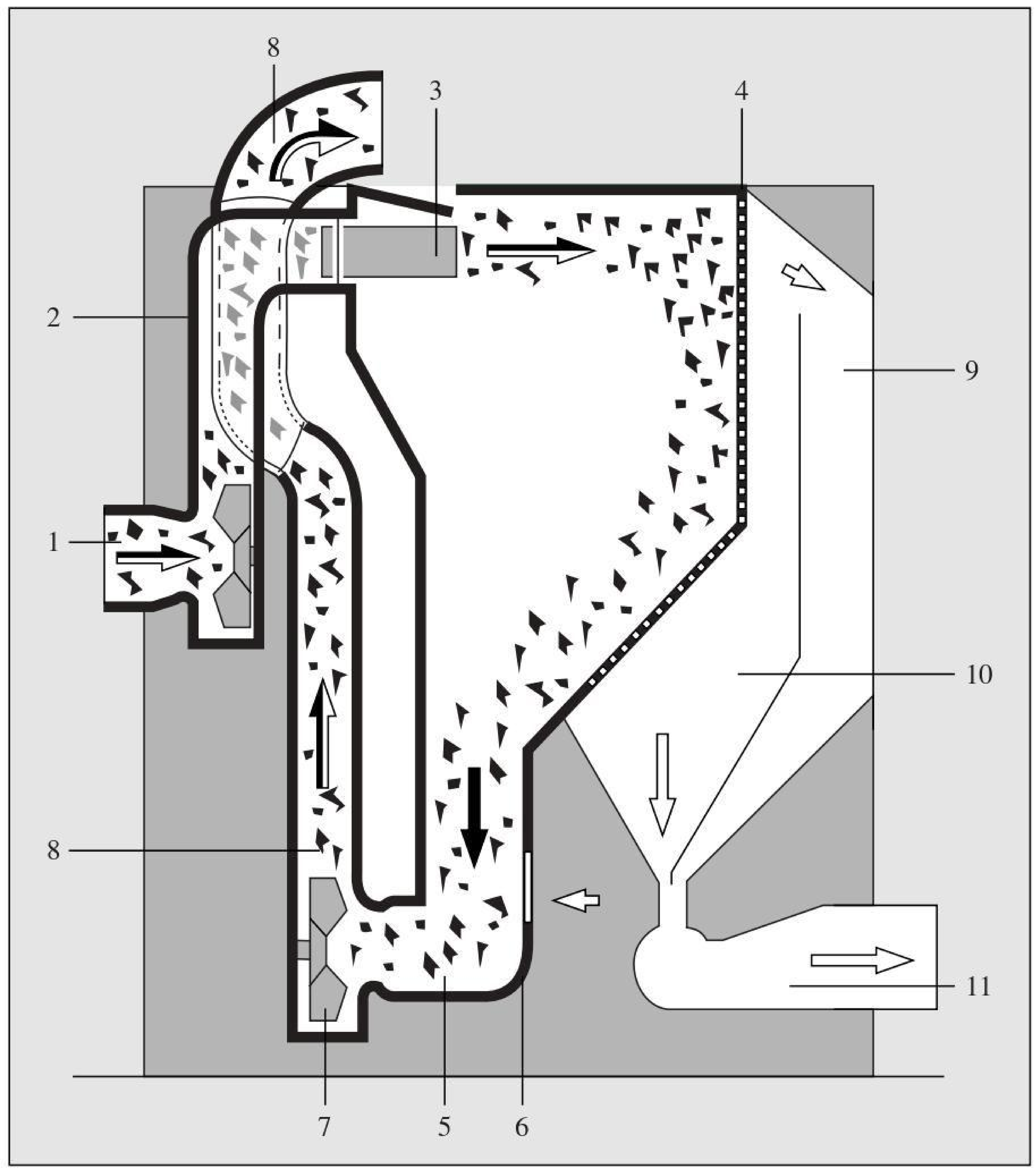
Beater type	Description	Intensity of opening
Buckley	A bladed beater that may be used in the early stages of opening. The number of blades varies from 20 to 32.	Typically, tuft sizes can be 500 to 600 mg (initial opening) or 85 to 100 mg.
Kirshner	This has three arms with wooden lags, each 11 cm wide. Each lag contains 1000 pins, 10 mm long.	Tuft size: 5 mg.
Saw-tooth	Usually, 1 m × 38 cm dia., with a tooth density of 2 per cm^2.	Tuft size: 0.88 mg.

$$n_f = \frac{I \times 10^5}{L_f \times T_f} \tag{2.2}$$

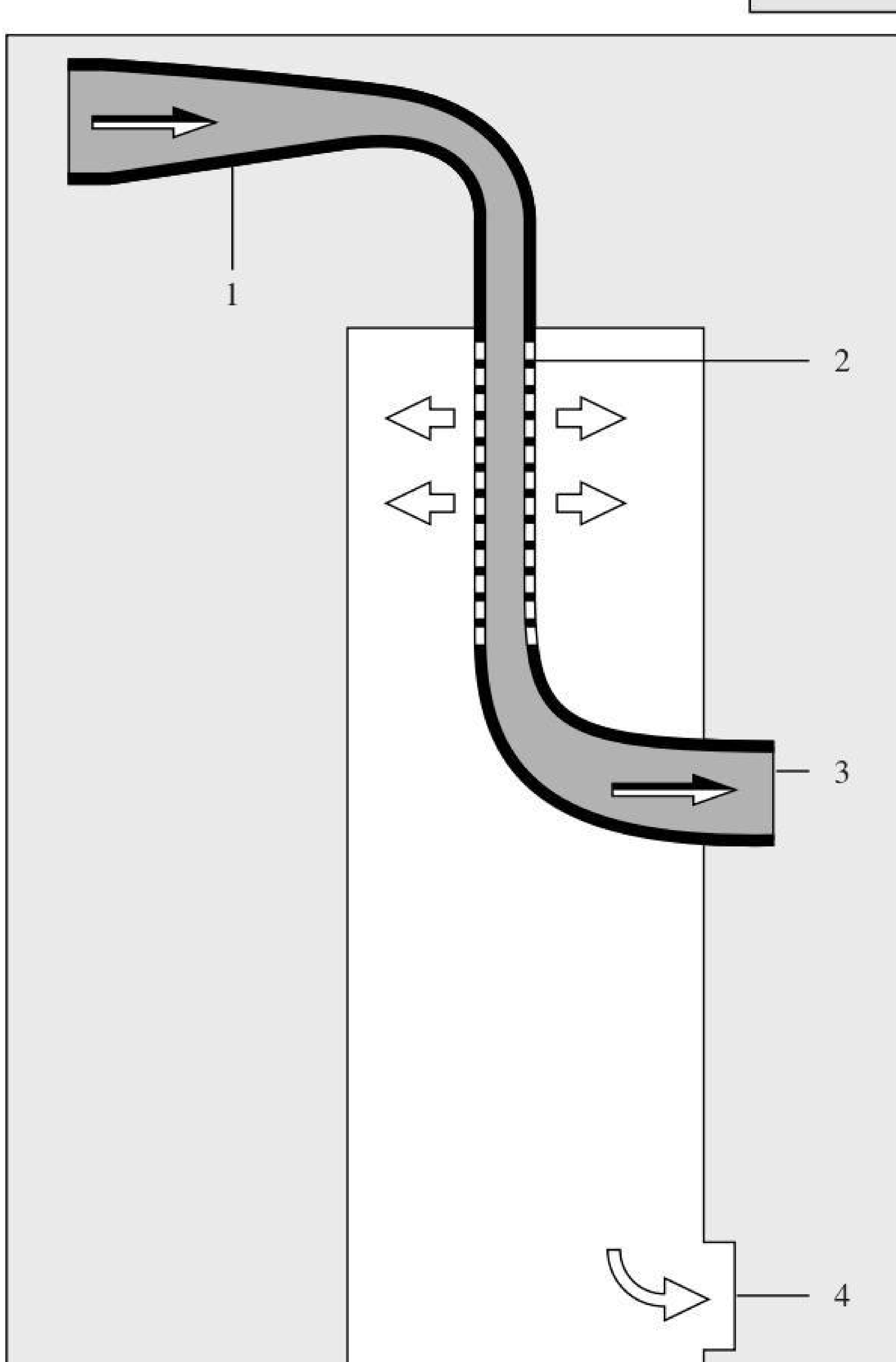
where L_f = average fiber length (cm)
T_f = average fiber linear density (mtex)



1 – Material Inlet
2 – Perforated Screen
3 – Adjustable Flap
3 – Material Exit
4 – Exit of Dust-Laden Air



1 – Material Inlet
2 – Perforated Screen
3 – Material Exit
4 – Dust Extraction



1 – Fan
2 – Material Feed
3 – Distributor
4 – Perforated Screen
5 – Suction Zone for Continued Material Flow
6 – Air Inlet
7 – Fan
8 – Material Flow
9, 10, 11 – Dust and Waste Removal

FIGURE 2.13 Dust removal systems. (Courtesy of Trutzschler GmbH & Co. KG.)

An alternative to tuft size (i.e., I) is the number of blows per kilogram, N_k.

$$N_k = (60 \times n_b \times N)/P \tag{2.3}$$

The I or N_k value gives an indication of the degree of treatment in that the more blows per kilogram of material, the smaller the tuft size and the more trash that is likely to be removed. However, the calculation does not take account of the effect of the space settings of the beater to the feed roller and of beater to grid, or of the grid spacing. The mechanical removal of trash and dirt particles is always accompanied by some loss of fiber; with cotton cleaning, the amount of fiber in the waste is referred to as the *lint content.* Usually, this is composed of short lengths of broken fibers, but poor processing can cause the loss of fibers of much longer lengths and/or a high level of fiber breakage. The objective is to optimize the machine settings (i.e., beater speed, production rate, and gap settings of the working components) to minimize the percentage lint and usable fiber length in the waste.

2.2.5.2 Openness Value

The more effectively the material is opened, the better the chance of trash removal and the lower the fiber content of the waste. The opening action primarily does two things. It reduces the fiber mass into small clumps (tufts), as described above, but it also loosens the tightness of packing of the fibers within each tuft, thereby reducing the tuft density or increasing its specific volume. In common parlance, we could refer to the tufts being more *fluffed up,* which describes their visual appearance. The openness value (OV) is a measure of how fluffed up the fiber mass has become on passing through a beater system, i.e., its degree of opening. Since we are concerned with changes in tuft density and want to account for different fiber densities, OV is defined as the product of the specific volume of the fiber mass and the specific gravity (SG) of the constituent fiber (or, for a blend of fibers, the sum of the product of their relative proportions and their SGs).[1]

Szaloki[1] describes a simple method of measuring the specific volume, in particular for cotton and short-staple mmfs. A sample of the fibrous mass is used to fill a 4000-ml Pyrex® beaker. A Plexiglas® disc weighing 200 g, with air-escape holes and having a slightly smaller diameter than that of the beaker interior, is placed on top of the sample in the beaker. After a settlement time of 15 to 20 s, the compressed volume is noted, the sample is weighed, and the specific volume in units of cm^3/g is calculated. Eight to ten measured samples are usually required for a 95% confidence level in the resulting data. Measured values[1] show a typical OV for the fiber mass in a bale of cotton at the beginning of an opening and cleaning line to be around 51 cm^3/g, while, at the end of the line, the OV can be greater 140 cm^3/g.

2.2.5.3 Cleaning Efficiency

This is the percentage of the impurities removed from the fiber mass. Hence,

$$CE = \frac{(W_{IN} - W_O)100}{W_{IN}} \tag{2.4}$$

where W_{IN} and W_O = respective mass values of the impurities in the fiber at the input and output to a machine or a sequence of machines

CE = cleaning efficiency

As referred to earlier, some unavoidable fiber loss occurs during mechanical cleaning. The settings of grid spacing will evidently control the fiber content of the waste. When considering this fiber loss, we can refer to the *effective cleaning (EC)* of a machine or a sequence of machines as

$$EC = \frac{(W_T - W_F)100}{W_{IN}} \tag{2.5}$$

where W_T = mass of waste

W_F = mass fiber in the waste

2.2.6 Wool Scouring

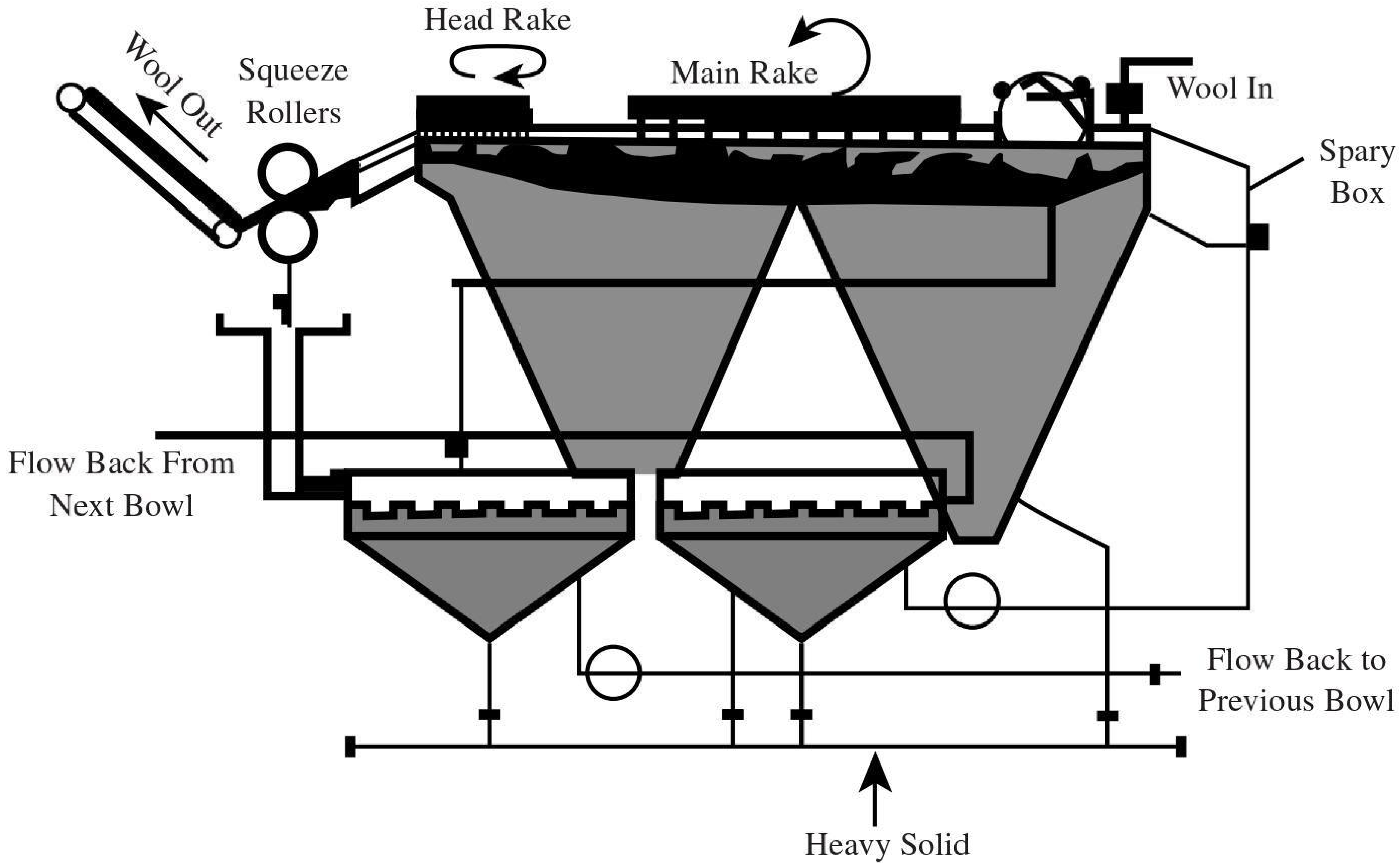
It was explained in Chapter 1 that raw wool contains particulate and nonparticulate impurities (e.g., dirt, squint, grease, soiling substances, and pesticides) that are removed by scouring. Vegetable fragments are also present and are removed either chemically by wool carbonizing and/or mechanically in the carding and combing processes of stages II and III (Figure 1.8, Chapter 1). Pesticides are used in sheep husbandry, and residues can remain in the fleece and be released when the shorn wool is scoured. Potential risks to the environment from pesticides have led to certain types (organochlorines and arsenic) no longer being widely used, and there is a move toward employing biodegradable chemicals that are applied in a controlled way to minimize residues.

Definition: Wool scouring may be described as a process by which a solvent or detergent is used as a scouring agent to remove grease, sweat, minerals, and other impurities from the wool fleece.

One of two methods may be used: solvent scouring or emulsion scouring; the latter is the most widely employed. The conventional emulsion scouring process involves a heated aqueous scouring solution, termed the *liquor,* in a set of two, three, or four scouring bowls (depending on the amount of impurities to be removed), and a warm rinse bowl. These are sometimes referred to as a *washing set,* and the first bowl is called the *main bowl.* Placed between consecutive bowls are pairs of rotating squeeze rollers. The liquor in the first bowl is at a temperature that is hot enough to melt the grease. The scouring agent is added to emulsify the grease. The amount of scouring agent in the heated water, the water temperature, and the wash time in each bowl decrease from the first bowl, with the last bowl being just a short, warm rinse (see Figure 2.14 and Table 2.2).

The wool is automatically fed from a hopper into the first bowl of the series. When the wool falls into the scouring liquor, the entrapped air among the fibers causes the wool to float, so a paddle-type roller (called a *rotary immersion drum,* a *ducker,* or *posser*) immerses the wool so it is thoroughly wetted (see Figure 2.14).

(a)



(b)

FIGURE 2.14 (a) Scouring blow with immersion drum and rakes (Courtesy of Andar Ltd.), and (b) schematic of scouring bowl showing liquor flow.

TABLE 2.2
Scouring Conditions for Merino Wool (Conventional System) — Average Yield 50 Percent

	Bowls			
Parameters	**1st**	**2nd**	**3rd**	**4th**
Temperature, °C (approximate)	54	51	49	46
Soap, percent by wt. of liquor	0.5	0.5	0.2	–
Alkali, percent by wt. of liquor	0.2	0.1	–	–
Time (minutes)	3	2.5	2	–

Courtesy of Brearley, A. and Iredale, J. A., *The Worsted Industry,* WIRA, Leeds, U.K., 1980.

Each bowl may be approximately one meter deep, and there is a perforated metal-sheet near the top of the bowl. This prevents the wetted-out wool from sinking to the actual bottom of the bowl. The wetted-out wool is then moved slowly forward, toward the opposite end of the bowl, by a set of forks in a harrow system. In more modern designs, rakes or rotating perforated "suction" drums are used. The forks or rakes move as a group so as to give the wool its forward movement, and their motion causes slight agitation of the wool mass. This assists the scouring action. However, excessive agitation can result in excessive fiber entanglement, i.e., *felting*.[17] The objective is to minimize the movement of fibers relative to each other so as prevent the interlocking of the scales on their surfaces. With suction drums, the wool is held against the drum as it is washed by the liquor flow, and it then floats near the liquor surface between the drums. Suction drums give gentle handling of wools, which minimizes any entanglement, particularly of fine wools.

Soap and soda ash traditionally have been effective scouring agents for wool, the last bowl of the washing set being a warm-water rinse to remove the soap and alkali. Importantly, modern scouring processes ensure that wool is left with a neutral pH balance.

Various synthetic detergents (nonionic and anionic) have been developed to replace soap. A few studies into the use of synthetic detergents have been published,[3–5] but commercial information is not readily available on scouring formulations of detergent and "builders" [i.e., added chemicals like washing soda (sodium carbonate)][6] to enhance detergent performance. Reported findings show that the percentage ratio of the scoured wool to the greasy-wool feed, termed the percent yield, can vary within 48 to 50%, depending on the alkalinity of the liquor. Neutral nonionic and soap-soda scouring gave high yields, but also high residual grease, and soap-soda was found leave residual dirt in the soured wool. Alkaline methods gave lower yields, the effect being greater for coarse wools. This is attributed to damage of the oxidized portion of the wool staple, i.e., near the fiber tips, by the warm alkaline liquor. Coarser wools have more open fleeces, which allows a greater length of the staple to be exposed to weathering and weakening by sunlight (photo-oxidation) than finer, denser wools (e.g., merino). Environmental considerations have led to nonionic/anionic biodegradable detergents replacing traditional scouring agents, with the claim by the detergent manufacturers of improved wetting and emulsification and of a gentler scouring action that can lead to reduced felting of the wool.

The hard dirt being washed from the wool is mostly detached in the first bowl to sink through the perforations in the false bottom. It is then continuously removed. The liquor flows counter to the direction of travel of the wool, compensating for the abstraction of water by the scoured wool and for water carried away with the effluent. The idea is also for the bowl prior to rinsing to have as low a level of impurities as possible, so released impurities should be transported back to the first bowl where they can be removed. The pressured rollers at the delivery end of each bowl squeeze the liquor from the wool. The liquor is filtered and recycled to the main bowl. This is important from the environmental viewpoint and for the process to be a continuous scouring system. When the wool is delivered from the rinse and squeezed dry, it should be lofty and soft, with a clean smell and residual grease content no greater than 0.75%.

Despite the use of the pressurized squeeze rollers, the wool leaving a washing set contains about 50% moisture, which must be reduced before further processing. Hot-air drying is frequently used (see Figure 2.15). The capacity for air to hold moisture increases with temperature, so, for efficient wool drying, the temperature must be sufficient to enable adequate moisture removal without scorching the wool, and the airflow rate must provide a sufficient volume of air to come in contact with the wool for effective moisture containment and transport by the air before its saturation point is reached. To achieve this, hot air at about 82°C is made to flow with or against the wool.

The gentle control of the wool during its passage through the bowls is important for minimizing fiber entanglement, which can present considerable problems in later processing. Fiber entanglement makes it more difficult to open the wool and to individualize fibers during carding. The more entangled the fibers, the greater the chance of fiber breakage and damage, resulting in considerable waste.[7,8] The higher the production speed in scouring, the greater the likelihood of fiber entanglement.[9] Therefore, the finer the wool, the lower the production speed and rate will be (see Figure 2.16). Large bowl widths, however, enable a greater mass throughput at low speeds and thereby facilitate higher production rates.

Research into various techniques for reduced felting during wool scouring has led to the use of high-pressure jets[4–11] and to methods for measuring fiber entanglement in scoured wool.[12–15] Jet scouring, as it is termed, was first used as a solvent scouring system;[16] wool does not felt when gently agitated in anhydrous solvents. Figure 2.17 shows that, instead of moving through bowls, the wool was transported by a traveling conveyor under jets of an organic solvent (white spirit). There were two solvent jet stages followed by two water jet stages for rinsing. The water jets displaced the solvent from the wool and dissolved the residual suint (perspiration salts), which is insoluble in white spirit. The sludge from the first bowls was collected and treated to separate the solvent from the grease so that the solvent could be

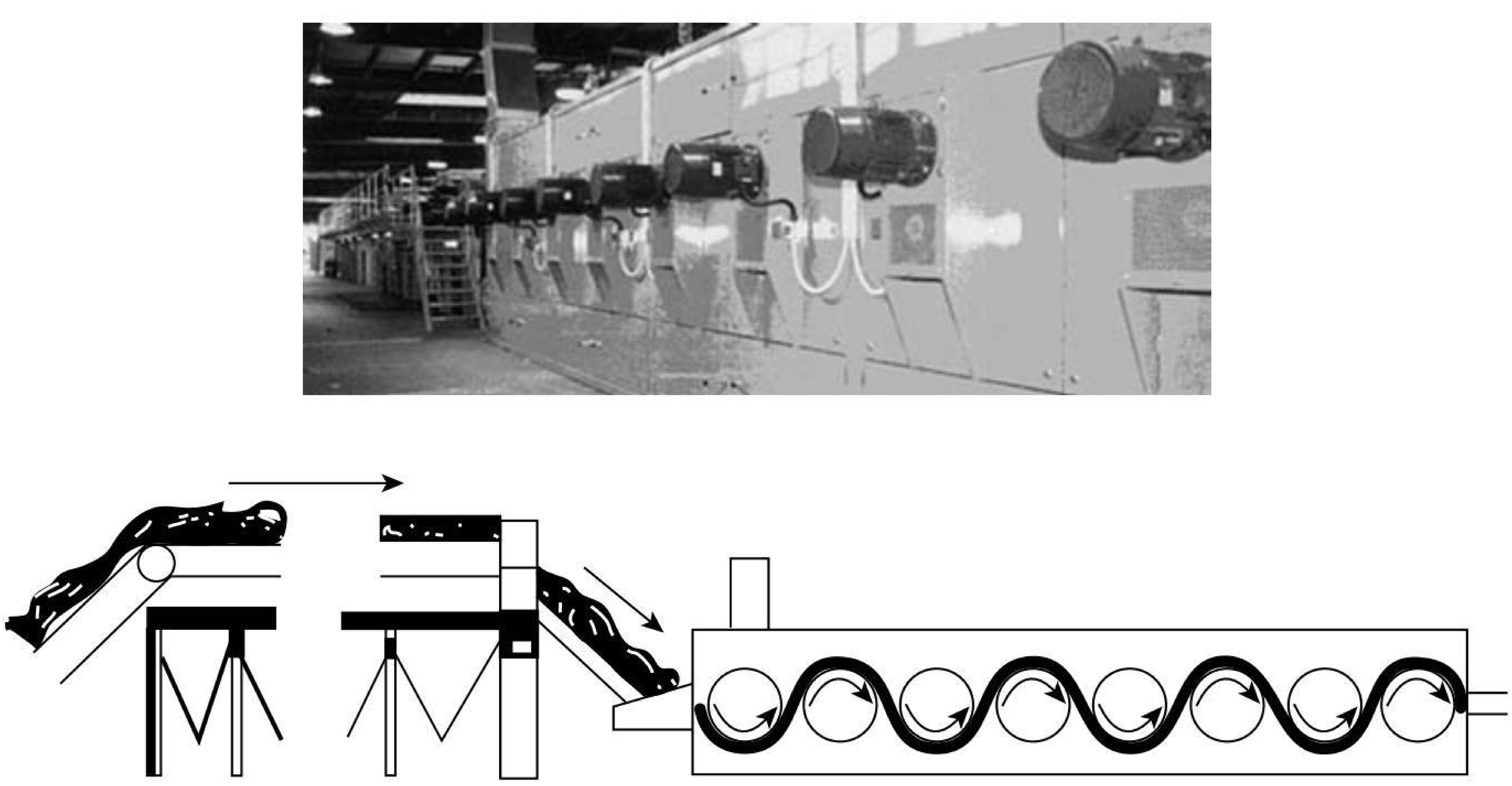


FIGURE 2.15 (a) Suction drum drying machine (Courtesy of Andar Ltd.), and (b) schematic of scouring line with suction drum dryer.

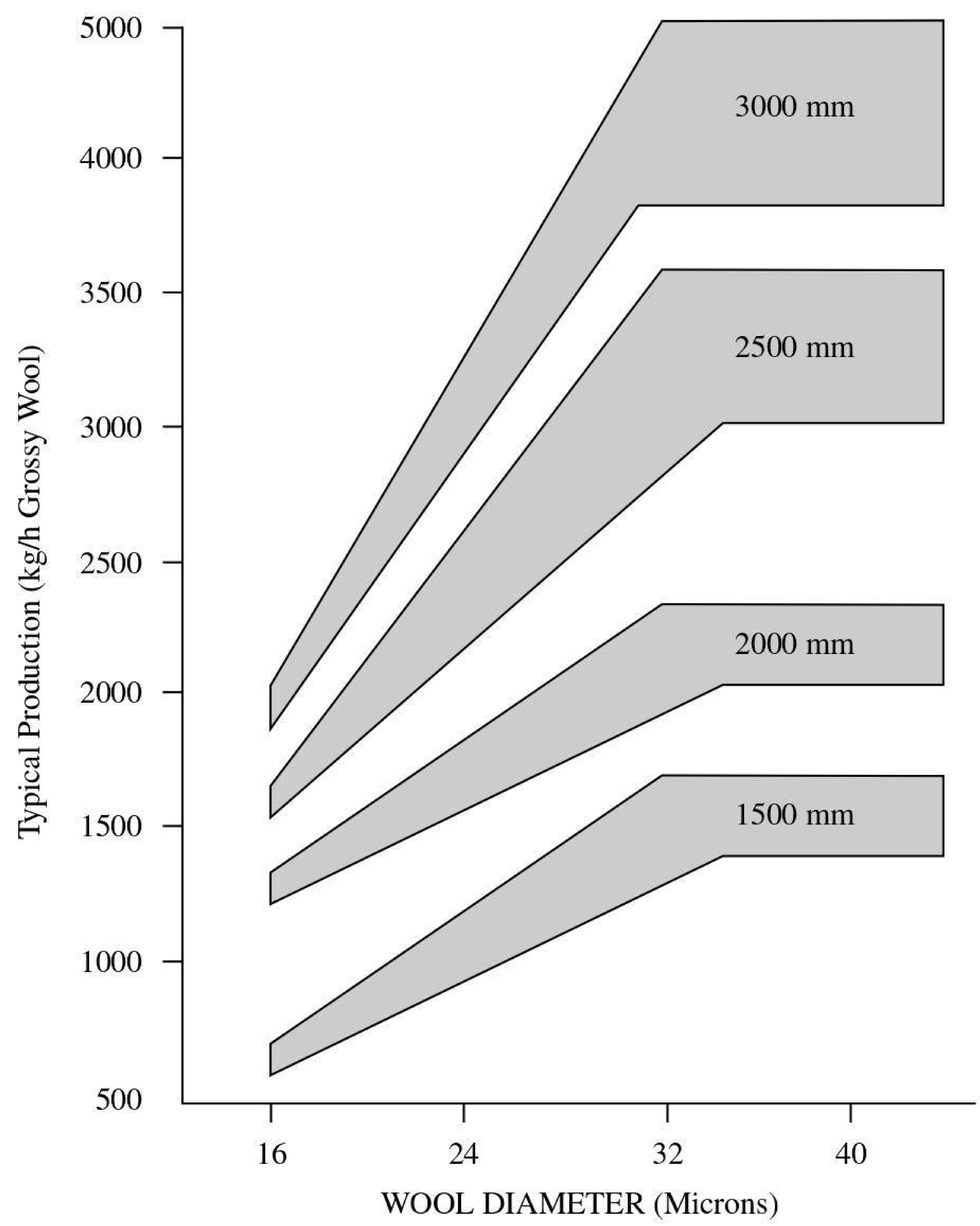


FIGURE 2.16 Plant capacity for differing working widths. (http://www.austehc.unimelb.edu/tia/287.html)

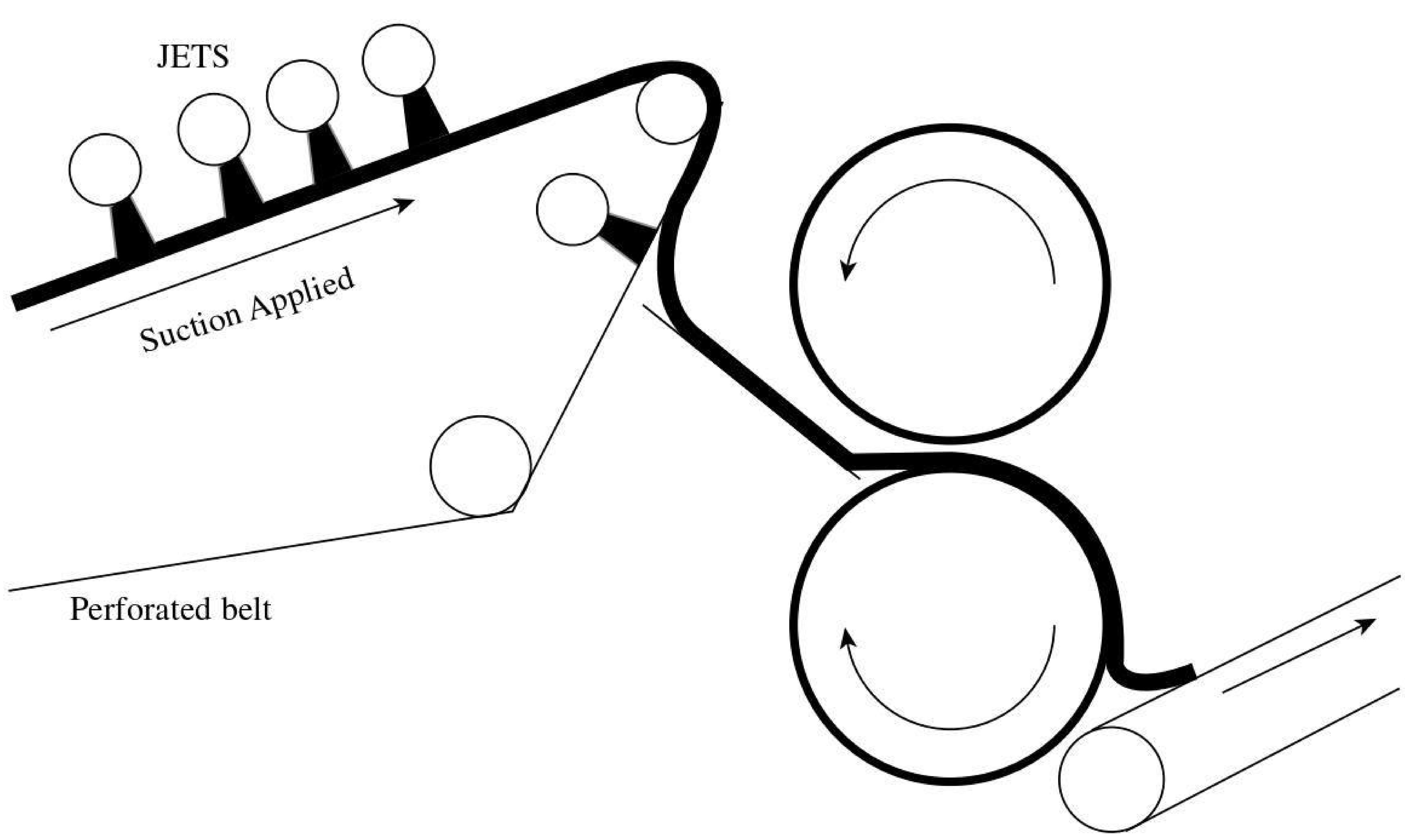


FIGURE 2.17 CSIRO jet scouring. (*Source:* http://www.austehc.unimelb.edu.au/tia/287.html.)

reused. This scouring system was less disturbing to the wool fibers and consequently resulted in lower entanglement and much reduced waste in the downstream process stages II and III (see Figure 1.8, Chapter 1). The disadvantages of using an organic solvent were the capital cost of the solvent recovery and the potential safety risks. The solvent agent was subsequently replaced with aqueous liquor containing a nonionic detergent. Jet scouring, however, has not replaced the conventional system because of its inferior scouring ability.[17]

Although freedom from entanglement is an important objective in scouring, the treatment of waste from the process has become increasingly important, because the pollution associated with emulsion scouring can be extremely high.[1] The related environmental problems have led to some renewed interest in solvent scouring.[18] One example of this is Wooltech (ICI-Triwool), which is a solvent scouring system based on trichloroethylene.[18] However, the wider practice is to use some form of effluent treatment of the waste from the emulsion scouring process.

During scouring, a large amount of impurity is removed from the wool [up to 450 kg/h (1000 lb/h)], mainly in the first bowl. The high content of organic impurities in the raw wool often means that emulsion scouring can result in high biological oxygen demand (BOD)[19] pollution waste. The wool grease can be recovered from the scour liquor as lanolin for cosmetics and pharmaceuticals, and doing so can reduce the BOD by 20 to 30%. Suint also can be recovered and used for detergent manufacture, and this extraction reduces the BOD by another 20 to 30%.[2,19] Continuous scouring processes operate under equilibrium conditions wherein there is a balance in the impurities entering the system from the wool, the contamination levels in the scouring liquor, and the waste removed from the system. With systems that are not designed for continuous operation, the contamination of the liquors increases to a level that is too high for adequate scouring to continue. Dirt accumulation eventually requires dumping of the liquor, even if counter-current flow is used to extend the scouring run. Published figures of average concentrations of impurities in the main scouring bowl for a conventional scour in which soap and soda are used indicate that the concentrations, after a few hours of operation, are 0.5 to 5.0% wool grease, 1% suint, 0.15 to 0.4% soap, and 1% dirt. The maintenance of equilibrium in the scour liquor requires the removal of the emulsified wool grease, which, if allowed to remain, reduces the scouring effect, irrespective of the pH. The suint from the wool that is deposited in the bowls is water soluble and forms suint soaps, which assist in the detergent action of forming emulsified wool grease. As much dirt as possible must also be removed from the scour liquors because of the tendency for it to be redeposited onto the wool, causing a dirty scoured wool mass to be produced. Continuous scouring therefore usually incorporates centrifuge cleaning of the liquor for dirt removal to allow processing to continue.

Ideally, continuous process features multistage, counter-current water flow with in-line facilities for wool grease and dirt removal from the scouring liquor. Several different means may be employed to remove wool grease and dirt from scour liquors,[20,23] such as evaporation, acid cracking, centrifugal separation, hypochlorite process, calcium-ion-carbon dioxide process, froth flotation, aeration, and solvent treatment. Centrifugal separation is, however, the simplest. Since the degreased liquor from this process will still retain the suint and much of the detergent already used, it offers the advantage of simpler liquor recycling to the scouring bowl and, with metered topping up of the detergent concentration, significant savings on detergent costs (20 to 30%) can be realized.[2]

Centrifugal separation fractionates the wool grease into the auto-oxidized grease from the fiber tips, which remains emulsified in the degreased liquor, and the un-oxidized grease, which is the recovered product. The oxidized grease has a higher acidity, darker color, and is more sensitive to heat. Centrifugation, therefore, gives a good by-product. The technological principle is the mechanical separation of particles by centrifugal force according to density differences. Pretreatment by coagulation or flocculation may be necessary to increase particle size and separation efficiency.

Figure 2.18 illustrates the basic arrangement of a centrifuge system. The main components and ancillaries consist of rotary filter screens for each bowl (membrane filtration may be used for the rinse bowl), a settling tank (C) located underneath squeeze rolls, and liquor-reclamation equipment employing hydrocyclones (A) and centrifuges (B). Removal of fiber contaminants by the filter screens precedes particle solids removal. Heavy solids removal can be by either gravity via a settling tank, in which a flocculate can be employed, or by hydrocyclones as depicted. Sirolan CF, developed by CSIRO, is one example of a chemical flocculation process.[21] It is reported to be effective as a first-stage treatment for the heavy waste. Table 2.3 shows report results of high removal efficiencies for BOD and COD. The sludge discharge may be dewatered to the state of a spadeable solid that is suitable for composting or palletizing, or the slurry disposed of by incineration.

TABLE 2.3
Typical Results for Sirolan CF

	SS concentration (%)	BOD (mg/l)	COD (mg/l)
Feed	3.5	11000	59000
Concentrate	0.03	2800	11500
Removal efficiency (%)	95+	75	80

SS = suspended solids (dirt, wool grease, etc.), BOD = biological oxygen demand, COD = chemical oxygen demand.

The removal of a high percentage of wool wax and particulate matter from the heavy waste facilitates further treatment of the effluent. This involves the temperature of the resulting grease emulsion being increased to about 95°C by a heat exchanger and specially designed jacketed storage tanks where the emulsion cracks thermally and dirt remnants and water are removed. The degreased liquor is then recycled to the first scouring bowl after being cooled via a heat exchanger to the operating temperature of the bowl.

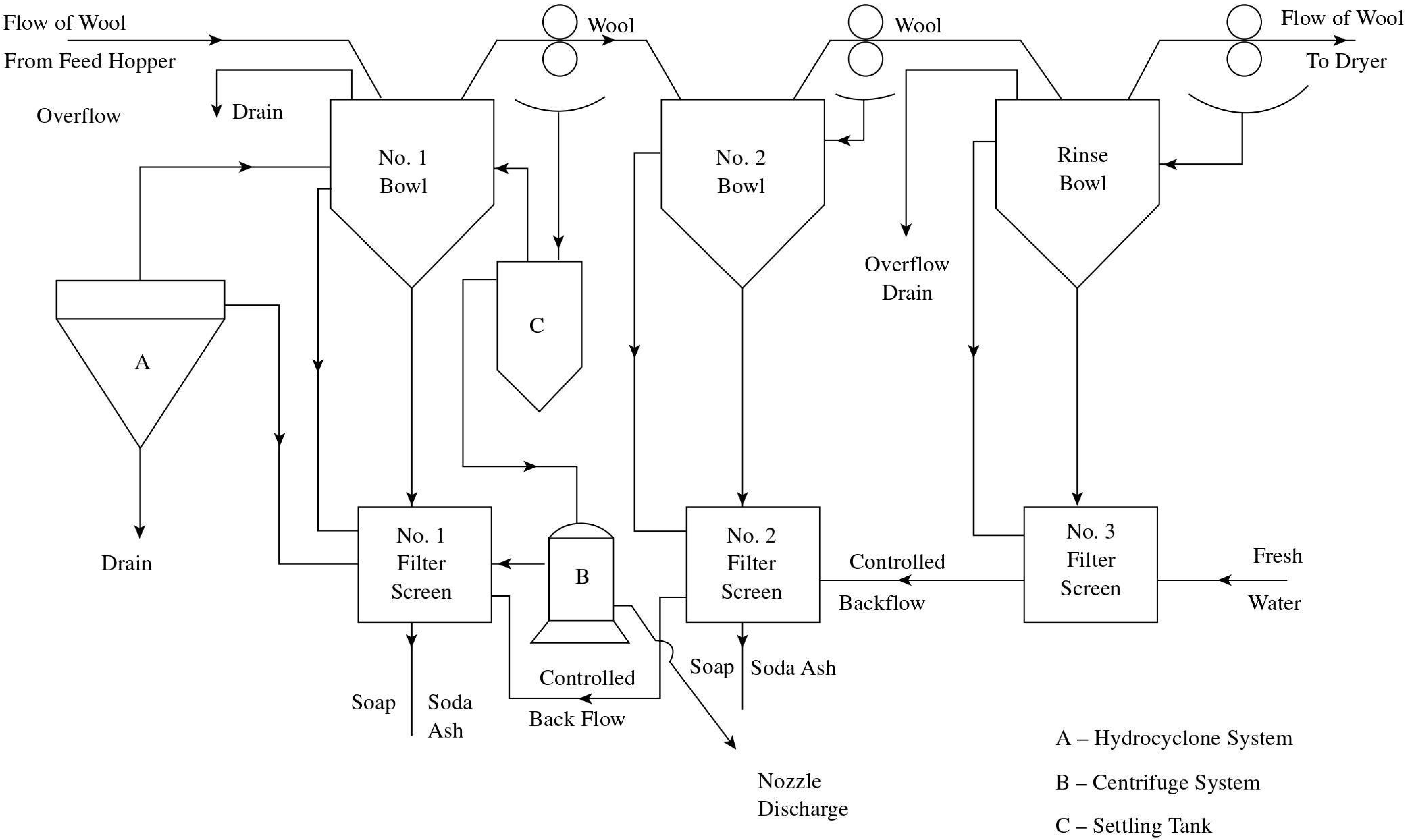


FIGURE 2.18 Basic arrangement of a centrifuge system. (Courtesy of McCracken, J. R., Samson, A., and Chaikin, M., "The Systematic Optimization of the Aqueous Compression-Jet Wool Scour: Part 1 Pre-Optimization Procedures," *J. Text. Inst.*, 63(1), 1972, 1–23.)

A number of commercial wool grease recovery and effluent systems[17] employ techniques that are variants of the above basic description. The well known ones are the Wool Research Organisation of New Zealand (WRONZ) system, Siroscour,™ and Sirolan Scour Waste Integrated Management System (SWIMS).[21] Essentially, the WRONZ system is for coarse wool scouring operations and requires two-stage centrifuging, whereas the other two systems are suitable for fine wool and require three-stage centrifuging. The trend in the design of effluent treatment plants is toward "no aqueous discharge," with the recovered liquor being fully recycled to the scouring line. Sirolan SWIMS falls within this category and is seen as setting a standard for future wool scour waste treatment systems.

2.2.7 Wool Carbonizing

In worsted processing, vegetable fragments such as burrs, seeds, and straw are preferably removed by mechanical means, whereas the higher vegetable content of lower-quality wools used in woolen processing requires both chemical and mechanical means. The chemical treatment is called *wool carbonizing* and is carried out on the scoured wool mass.

Definition: Wool carbonizing is the application of mineral acids to scoured wool to convert vegetable impurities into a black brittle hydrocellulose, making them more easily removable by mechanical means.

Following emulsion scouring, the loose wool is passed through bowls containing diluted sulfuric acid (5% H_2SO_4) at room temperature. The wool is then squeezed and hot dried (115°C) to concentrate the acid to degrade the cellulosic contaminants. Crush rollers and shaking subsequently crush the impurities to fragments and dislodge them from the wool fibers. The wool is then neutralized in a bowl of alkali solution and rinsed and dried. If severe treatment with the sulfuric acid is used to deal with, say, a sizeable amount of vegetable matter, considerable fiber damage may result.[28]

Carbonizing tends to weaken fibers. Strength losses range from 15 to 40% and, owing to broken fibers, can result in increased loss of useful fiber (5 to 20% by weight) during subsequent mechanical processing. The ideal would be if the wool absorbed no acid while the vegetable matter absorbed enough to be decomposed. Since the ideal cannot be achieved, the objective is to keep the amount taken up by the wool to a minimum. Wool and vegetable matter can take up acid chemically (sorption by functional groups) and physically (by absorption). In the carbonizing bath, the acid pickup of vegetable matter is almost all by absorption, whereas, with wool, absorption is around the 50% level.[29] At moderate temperatures, vegetable matter tends to absorb the acid liquor (acid + water) at a faster rate than wool and therefore becomes saturated in a much shorter time. Strength loss of wool becomes of importance for absorbed acid content of 5.5% and above. Reportedly,[30–34] detergents can be used to restrict the penetration of acid into the wool fibers without impairing the acid absorption by the vegetable impurities. The actual weakening of the wool occurs during drying and depends on temperature rather than drying time; below 50°C, the loss in strength is negligible, but drying time will be long; much higher temperatures with fast drying times are therefore used.

2.2.8 Tuft Blending

The blending of fibers is an important part of spun-yarn technology. Fibers are blended for many reasons, but in particular for one or more of the following:

- *To produce a uniform product.* There are usually significant variations in fiber properties among bales of the same fiber type or grade, and from one part of a bale to another. Such variations will be greater for natural fibers than for man-made fibers. Blending of the fibers within and among bales is therefore essential to obtain consistent yarns properties — especially mechanical properties, minimum variation in thickness along the yarn length, and uniformity of count and optical properties with regard to color when dyed. Dyed fibers are also blended, particularly for woolen yarns, and here consistency of shade is a requirement.
- *Reduce production cost.* Fiber cost is usually the major contributor to yarn cost and, in an ever increasingly competitive global textile market, product cost and product quality are key factors. Technical skill is required to keep fiber cost as low as possible without incurring unacceptable reductions in yarn quality. Blending of different grades is often used to reduce cost, but, in choosing the percentages of the different components, an understanding is needed of the effect of fiber properties on process performance and on yarn properties to ensure that the mixing of the different grades produces a uniform product. The effects of fiber properties on spinning performance and yarn properties are considered in the later chapters.
- *To enhance specific properties.* Consumer demands for easy-care clothing, improved comfort, and fashion have led to many blends of natural and man-made fibers. Most are two-component blends, but there is increasing interest in multicomponent blends and blends for special effects. In the technical textiles market sector, yarns may be spun from blends of up to five components (e.g., Kevlar, Nomex, PANOX, Wool, and PVC), where blend percentages for certain components can be as low as 1 to 5%. Again, the blending process must produce a uniform product.

In a well blended mass of fibers for spinning, the individual fibers of the different blend components should be present in the required proportions and well intermingled throughout the fiber mass. Certain operations in the process stages I to III play a part in achieving a well blended fiber mass, and therefore blending begins in stage I with the mixing of tufts.

At the start of opening and cleaning lines, bales of fibers of different grades or types are arranged in a *mixed laydown,* and tufts are removed from the bales and blended and then assembled to provide a homogenous feed to stage II in the production sequence. This means that, at any cross section of the assembled fiber mass fed to carding, the relative proportions of the different grades or types remain consistent.

A tuft, as we learned earlier, may consist of many fibers. Therefore, to obtain a yarn of a homogenous blend of fibers, blending must also occur downstream of opening and cleaning, where the intermingling of individual fibers can be realized. However, to achieve a high degree of fiber blending, there needs to be a high degree of tuft blending. Since blending progresses through to the spun yarn, at any cross section of the yarn, the relative proportions of the different fibers (grades or types) should remain constant. Therefore, the yarn properties should be consistent.

Definition: Tuft blending is the mixing of fibrous tufts removed from a bale laydown to produce a homogenous stock for consistency of yarn properties.

2.2.8.1 Basic Principles of Tuft Blending

From a practical viewpoint, the required proportions for a blend are determined by measured mass.

$$W_b = w_1 + w_2 + w_3 + \dots + w_n \tag{2.6}$$

$$= \Sigma\, w_i \tag{2.7}$$

and

$$p_1 = w_1/W_b \text{ or } p_i = w_i/\Sigma\, w_i \tag{2.8}$$

where W_b = the mass of the blend, and
w_i, p_i = the mass contributions and blend fractions of the fiber components for $i = 1$ to n components

In preparing to blend different fiber types or grades, it useful to estimate the average fiber characteristics of the blend that will influence yarn properties and spinning performance — in particular, the mean length, fineness, and strength. Table 2.4 gives the relevant equations. Lee and Kin[35] and Kang and Lee[36] describe how such equations may be used in the application of linear programming for formulating blends of cotton and of wool.

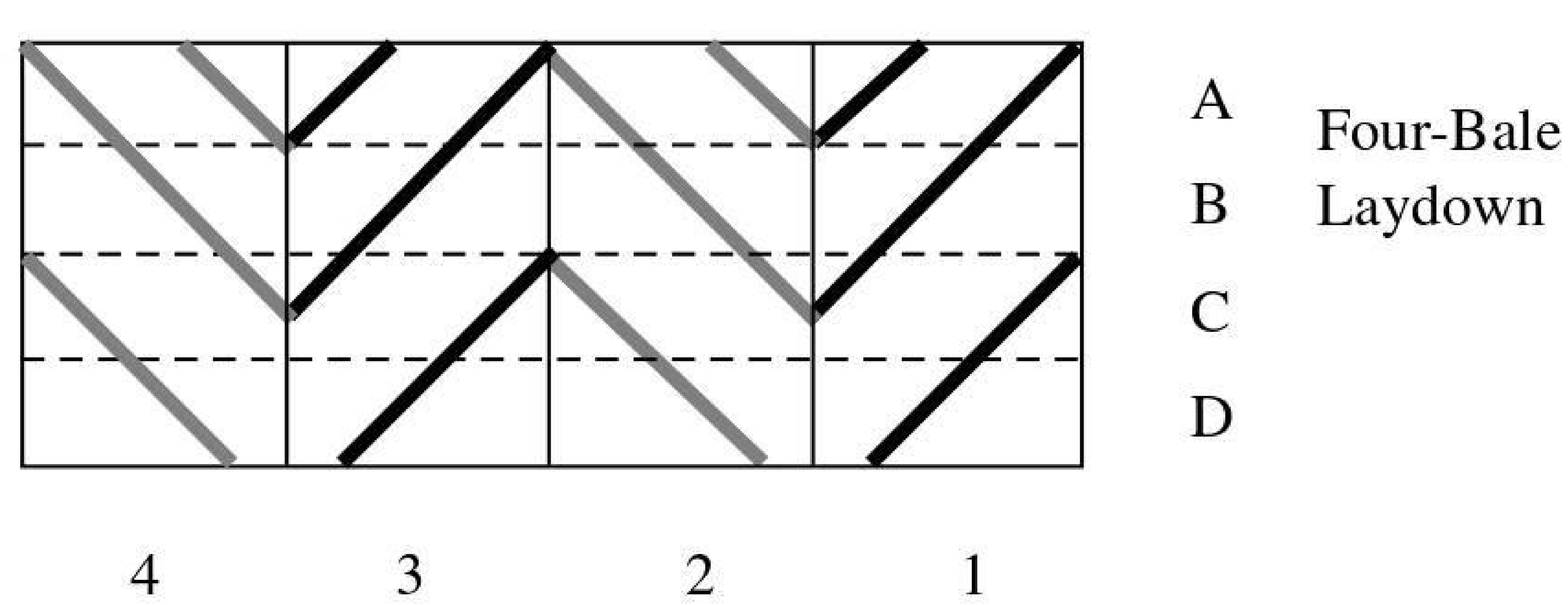
An important point to consider is the number of bales to have in a laydown for a blend. The minimum number can be easily calculated, as it is directly related to the number of different fiber properties and the proportions of each type to be blended.[37,38] For example, if a blend of cottons were to comprise three different micronaire values, two grades, and two different staple lengths, all blended in equal proportions, then a minimum number of 12 bales would be required in a laydown. The best degree of tuft blend is, however, achieved with the maximum number of bales in a laydown, which may be limited by practical constraints such as floor space and operational logistics.

At the start of the opening and cleaning operation, tufts are continuously removed from a laydown of bales. We can effectively visualize this as a layer of set thickness being removed from each bale in sequence going up and down a row of bales. There will be a time cycle in moving from one end of the row to the other and returning. The layer thickness removed is an important factor for optimum blending as is illustrated in Figure 2.19.

TABLE 2.4
Formulation of Fiber Blends

Fiber characteristics		Blend equation
Fineness:		
	Diameter (μ)	$d_m^2 = \Sigma\, p_i d_i^2$ where d_m = mean of the blend, p_i, and d_i = the proportion and mean diameter for each blend component for $i = 1$ to n components
	Count (mtex)	$f_m = 100/[\Sigma\, q_i/f_i]$ where f_m = mean of the blend, q_i, and f_i = the percentage and mean count for each blend component for $i = 1$ to n components
Length		$L_m = \Sigma\, p_i\, L_i$ where L_m = mean of the proportion and mean length for each blend component for $i = 1$ to n components
Strength		$S_m = \Sigma\, p_i\, S_i$ where S_m = mean of the blend, p_i, and S_i = the proportion and mean strength for each blend component for $i = 1$ to n components

Note: The table is not a comprehensive list of the properties accounted for in blend formulations; color is an important factor. For wools, the degree of bulk, the amount of medullation, and vegetable contaminant (VM = vegetable matter) are also used as blend parameters.[37]



B1	D1
B2	D2
B3	D3
B4	D4
A4	C4
A3	C3
A2	C2
A1	C1

1 - One stack-layer at a time dropped onto a moving conveyor

D1	D2	D3	D4	C4	C3	C2	C1
B1	B2	B4	B4	A4	A3	A2	A1

2 - The bales now have 8 layers A to H, each half the size of the above, and with two stack-layers at a time dropped onto the moving conveyor to give:

H1 / H2	H3 / H4	---------	---------	---------	---------	E4 / E3	E2 / E1
D1 / D2	D3 / D4	---------	---------	---------	---------	A4 / A3	A2 / A1

FIGURE 2.19 The basics of tuft blending.

For ease of explanation, we will assume a four-bale laydown and that the bales are of the same density and have an equal number of fibers. The only difference between the bales is that the fibers are dyed different colors. Layers of fiber mass are removed sequentially from the bales in the form of tufts, which are plucked from the bales at a fixed rate. We will also assume that the same thickness of layer is removed from each bale and that the thickness is such that a total of four layers are removed from a bale. These four layers are represented by the letters A, B, C, D in Figure 2.19, Four-Bale Laydown section. For the first bale, which comprises dyed-red fibers (column 1), the layers are A_1, B_1, C_1, and D_1. A similar notation is used for the remaining three bales (green, blue, and yellow, represented in columns 2 through 4). All four A layers (A_1, $A_{2,}$ $A_{3,}$ and A_4) are first removed and stacked consecutively, one on top of the other. The B layers are then stacked on top of the A layers. A new stack is then started with the C layers and finished with the D layers placed on top. If we now remove the bottom layer of the two stacks, one on top of the other, we will be blending A_1 and C_1 tufts, and, by progressing up the stacks we eventually will be blending B_1 and D_1 tufts. This gives a degree of blending of tufts from various parts of the same bale. Clearly, the smaller the layer thickness, the more layers that can be removed per bale and the higher the degree of within-bale blending.

If two thin layers at a time are moved from each stack and sandwiched, blending will occur between, as well as within, bales 1 and 2. By reducing the layer thickness and increasing the number of stacks, it should become evident to the reader that, subject to practical limits, blending improves with an increased number of stacks and layers per stack, and with the number of layers in each drop from a stack.

2.2.8.2 Tuft Blending Systems

Blending of tufts is carried out either gravimetrically (weight blending) or volumetrically (volume blending). Therefore, with respect to tuft size, it is important to take into account the density and moisture regain of the fibers. Tufts are often transported between machines of an opening line by airflow through ducting, and the uniformity of the tuft flow depends on the specific volume of the tufts. This parameter is a function of fiber density, moisture content, and the degree of openness of the blend components. Blend nonuniformity may arise as result of sizeable mass variations occurring after the start of the blending process. These variations can be the result of a drift in moisture content. As a result, bales of material for blending should be brought to the atmospheric conditions to be used in processing.

There are essentially four methods of tuft blending that follow the basic principle outlined in Figure 2.19,

a. Stack blending
b. Hopper blending
c. Batch blending
d. Continuous blending

The first two methods are gravimetric procedures, and the last is volumetric; method c is a combination. Continuous blending is the more advanced technique and is widely used in short-staple mills, whereas all four systems can be found in the processing of longer staples. This is particularly so in woolen mills, where much smaller batches of material are often processed, and capital investment has a longer replacement cycle. During blending, lubricants may be applied to the fiber mass as a processing aid for the downstream stages of II, III, and IV. Lubricants are usually applied only to wool fibers, since, with the removal of wool grease in scouring, the frictional characteristics of the fiber present difficulty in further processing. Cotton fibers have a wax film coating, and surface finishes are applied to man-made fibers during their production. A short account on lubricants is given in Appendix 2A.

Stack Blending

This is the simplest method for blending small amounts of fiber mass. It is carried out manually. First, the total quantity of each blend component is weighed. Then, by removing large tufts (sometimes referred to as *flocks*) from the weighed material, each component is spread, one on top of the other, over a wide floor area, while a predetermined percentage of processing lubricant necessary for the carding in stage II (Chapter 1, Figure 1.8) is uniformly applied between each layer. Only a single stack is built, so vertical slices are removed from the stack and fed to a mixing bale opener to be opened into smaller tuft sizes.

Hopper Blending or Automatic Weigh-Pan Blending

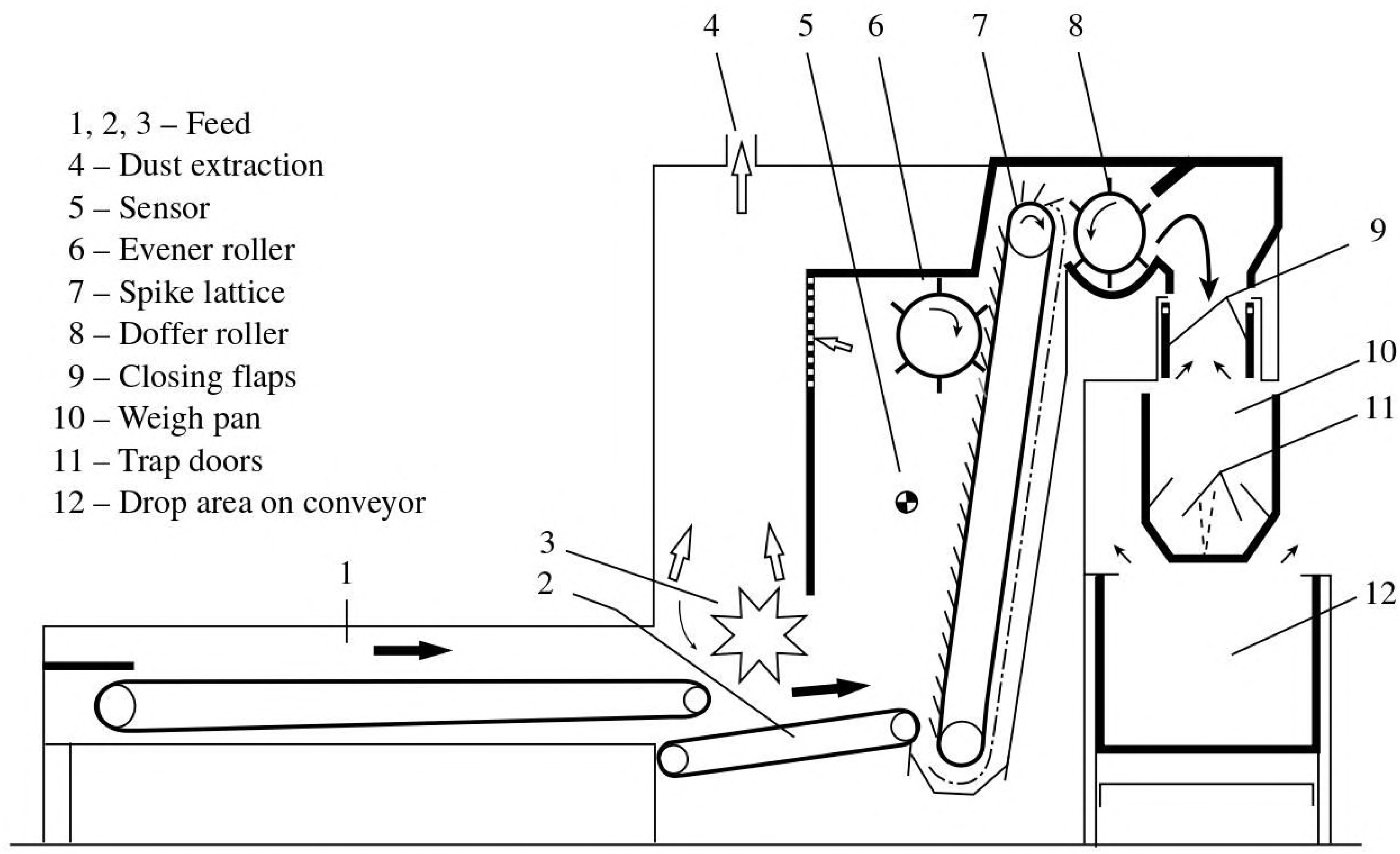
This method involves a weigh-pan fitted to the exit of a mixing bale opener, described earlier (see Figure 2.20a). The tufts removed from the spiked lattice by the stripper roller accumulate in the weigh-pan until a preset weight is reached, triggering the "closing flaps" and the opening of the weigh-pan. The accumulated tufts drop onto a transport belt. The emptied weigh-pan closes, and the "closing flaps" reopen; the cycle is then repeated. For blending to occur, several such mixing bale openers are arranged in parallel, as shown in Figure 2.20b, to make drops on the transport belt, which moves intermittently so that a drop from one machine falls on top of the drop from the prior machine to form a small stack of sandwich formation at the end of the line. Sprays for applying lubricants can be fitted to operate synchronously with the transport belt. The small stacks are subsequently fed to a further opening machine.

Batch Blending

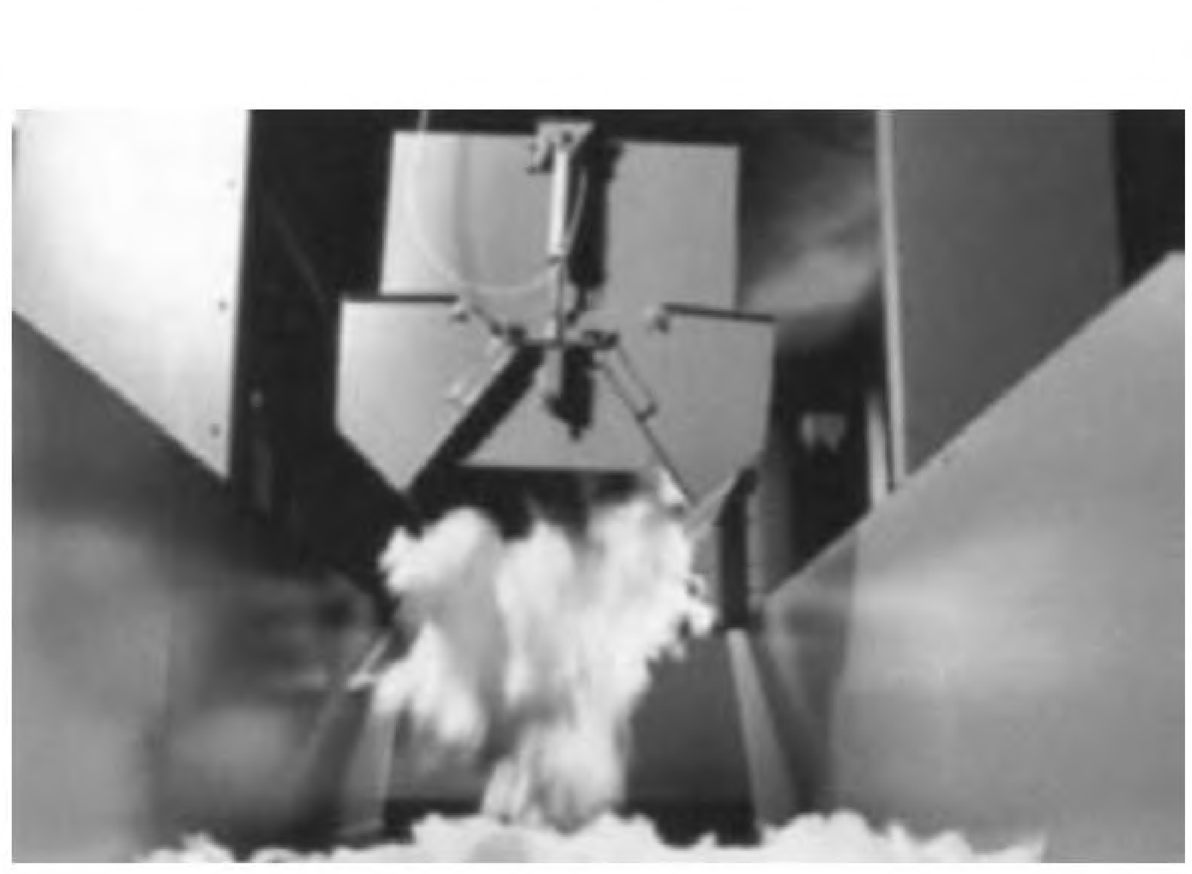
A traditional method employed in woolen mills, batch blending is basically a scaled-up version of stack blending. The process requires two opening units (e.g., Fearnought) and two or more blending bins arranged as indicated in Figure 2.21 and linked together by air ducting. Located at the top of the bins and connected to the air ducting is a rotating chute or spreader.

The components of the blend are fed in correct proportions into the first opening unit (A). With a Fearnought opener (see Figure 2.10), some amount of blending may occur in this initial stage of opening, but purposeful blending is carried out when the fiber mass has been sufficiently opened to give small size tufts. The tufts are transported through the ducting to the spreader of the first blending bin (B). As the spreader rotates, tufts are uniformly scattered over the floor of the bin, and they build up to form a large single stack. A significant degree of within-bale and between-bale blending can be achieved, depending on the floor area of the bin and the mass of the component layers fed from the bales. When the first bin is full, vertical slices are removed from the stack and fed pneumatically to the rotary spreader of the

(a)



(b) Arrangement of blenders



(c) Weigh pan drop

FIGURE 2.20 Automatic weigh-pan blending. (Courtesy of Trutzschler GmbH & Co.)

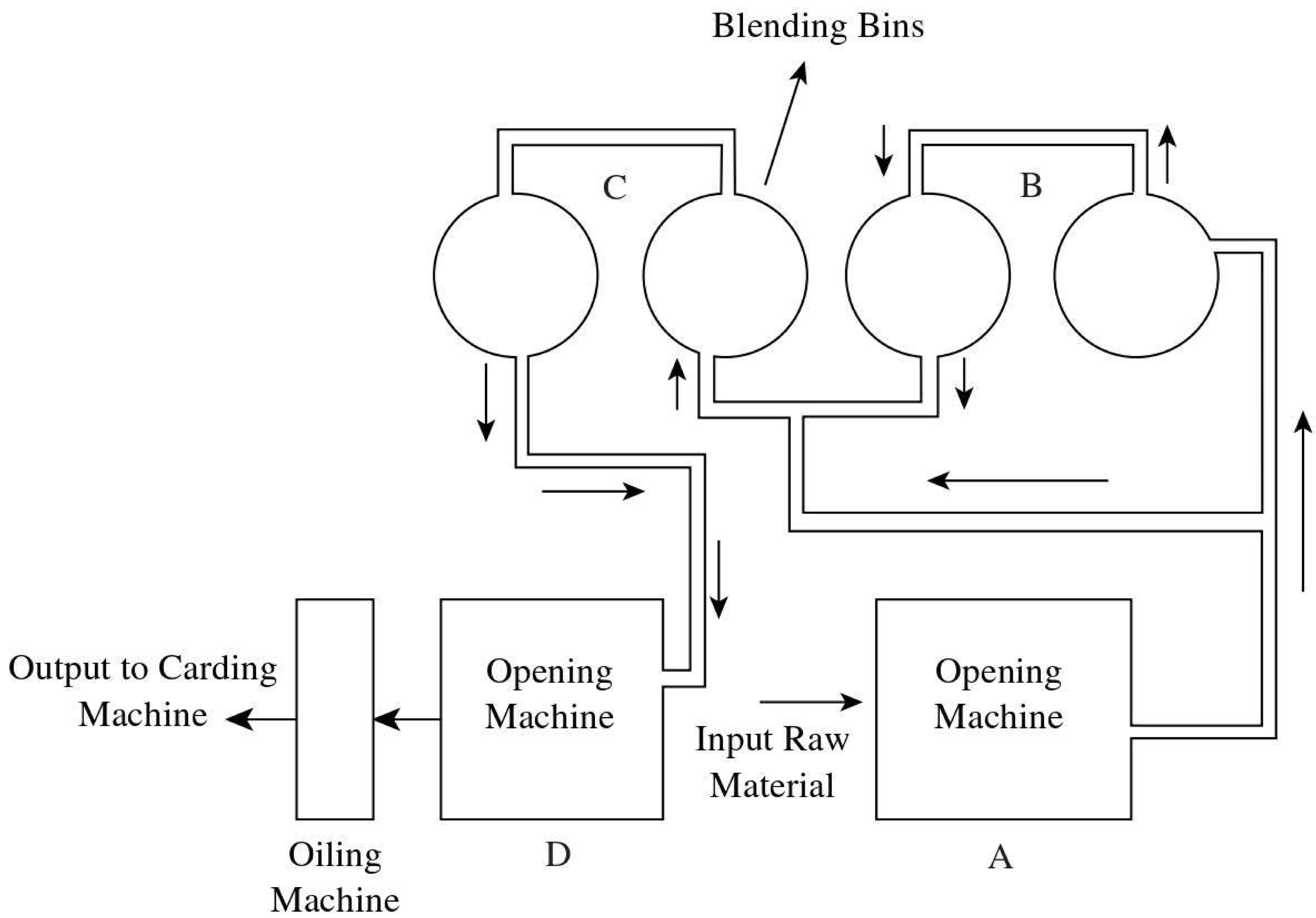


FIGURE 2.21 Batch blending.

second bin (C). The second stack formed has a much higher degree of within-bale and between-bale blending. Again, vertical slices are removed but this time are fed to the second opener (D), and lubrication is applied by an automatic unit to the material leaving this second opener. The blended material is then ready for the carding process of stage II.

Continuous Blending

Figure 2.22 illustrates a four-stack continuous tuft blender. Tufts are pneumatically fed into the top of each of four vertical parallel chutes. The chutes are filled successively, and the material is removed simultaneously from the bottom of all four stacks and dropped onto a belt conveyor, thereby producing a sandwich formation. The blend then may be pneumatically conveyed to a second such stack blender and /or onto a fine opener/cleaner prior to being fed for carding. There are various designs of continuous blending units — some with up to ten stacks. Others include a specially built belt conveyor, which enables a large sandwich formation and the removal of material in vertical slices from the formation to give additional blending.

2.2.9 Opening, Cleaning, and Blending Sequence

Figure 2.23 shows the stage I preparation sequence for wool fibers in worsted, semi-worsted, and woolen yarn manufacture. The main cleaning action is wool scouring but, as illustrated, mechanical cleaning to remove some particulate matter is incorporated prior to scouring.[37] The amount of dirt entering the scouring bowls is significantly reduced, resulting in lower volume of suspended solids and scouring effluent. In the semi-worsted and woolen process, blending is carried out after the wet treatment. The semi-worsted production route is not widely used for 100% wool processing, as will be explained later. One hundred percent man-made fibers are

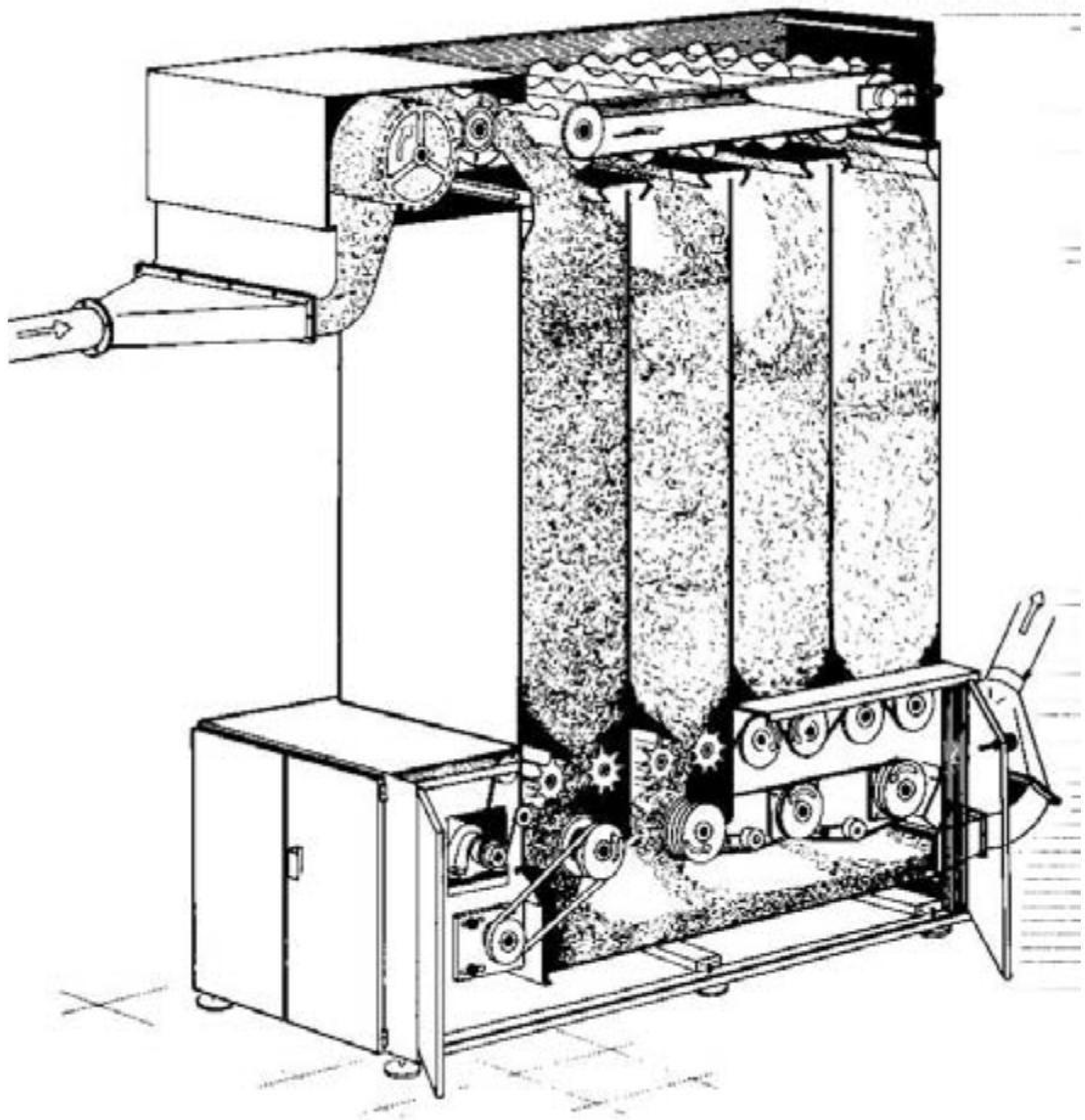


FIGURE 2.22 Four-stack continuous blending. (Courtesy of Marzoli.)

more frequently processed, in which case the opened fiber tufts are fed directly to blending. As explained in Chapter 1, the woolen yarns can be spun from recycled waste, largely wool fiber waste from the downstream processes, and the material usually is subjected to a carbonizing treatment to remove impurities.

Figure 2.24 illustrates a typical blowroom sequence for most cotton qualities. The automatic bale opener (a) produces small tufts from which dust and heavy particles are immediately removed, preventing fragmentation of the latter during intensive opening. A condenser drum (b) and the beater/grid-bar-airflow system (c) are used for this precleaning step. Following a multi-stack continuous blender (d), a multi-beater cleaner (e) is used for intensive opening and cleaning, and a final de-dusting step (f) carried out prior to feeding the material for carding.

In mechanical cleaning lines, control of the flow of the fiber mass from one machine to another can have a significant effect on the overall performance of a cleaning line. This matter has received much attention for short-staple blowroom processes and has led to the use of microcomputer control of material flow. Traditionally, the pressure switches and light barriers fitted in the feed zone (i.e., a hopper or bin) of a machine were used to switch the preceding machine on and off to prevent material overflow. The material throughput of machines fluctuated from zero to near maximal production speed with a significant downtime (i.e., when a machine is not running). For example, if the required production rate from a machine is 400 kg/hr and the downtime is, say, 50%, then the machine needs to operate at maximum rate of 800 kg/hr. This has often meant larger than optimal tuft size for effective cleaning, resulting in lower cleaning efficiency, or a more aggressive cleaning action with the associated increase in the fiber content of the waste. Modern blowroom machinery

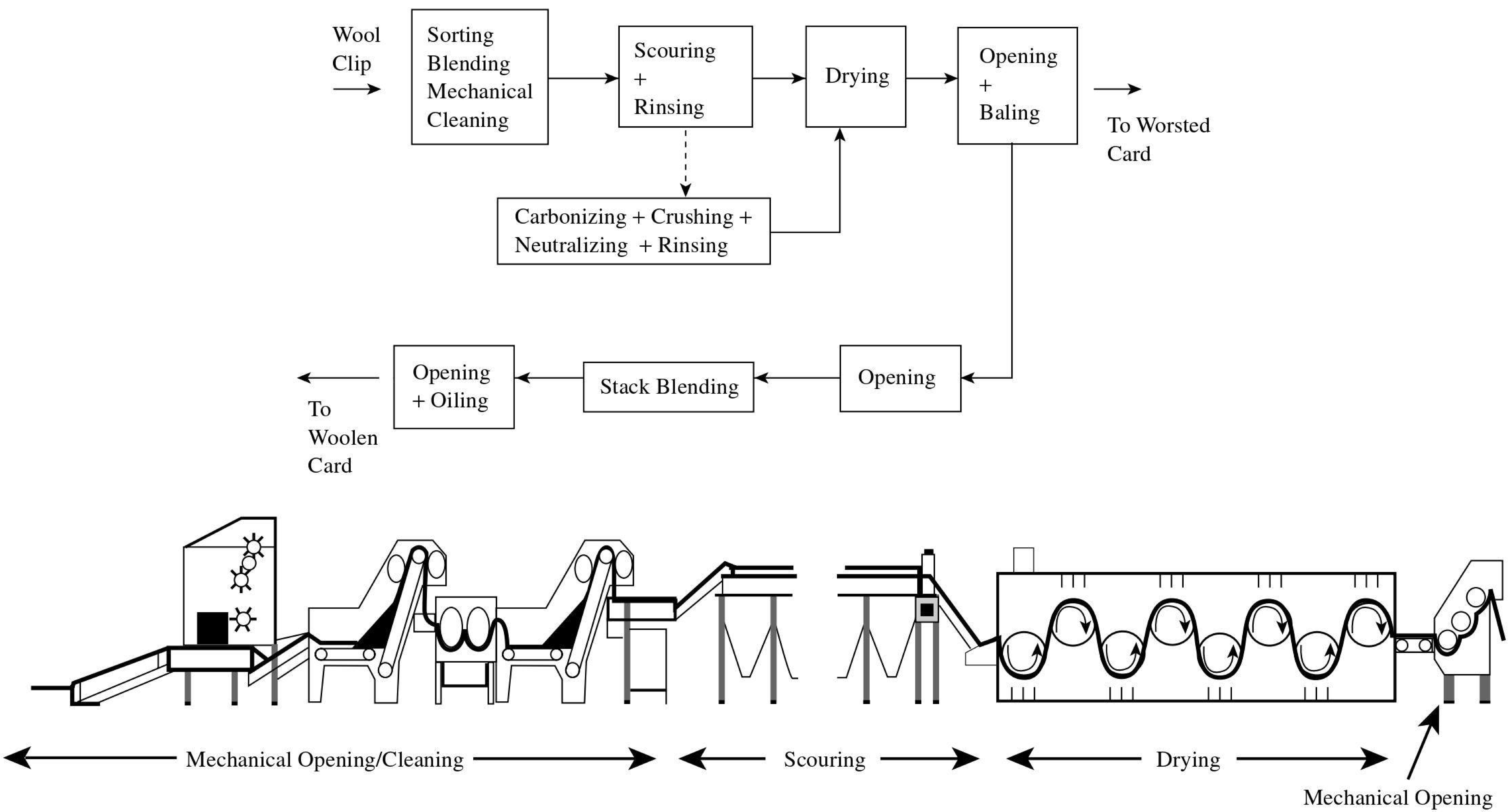


FIGURE 2.23 Stage I wool scouring sequence. (Courtesy of Andar Ltd.)

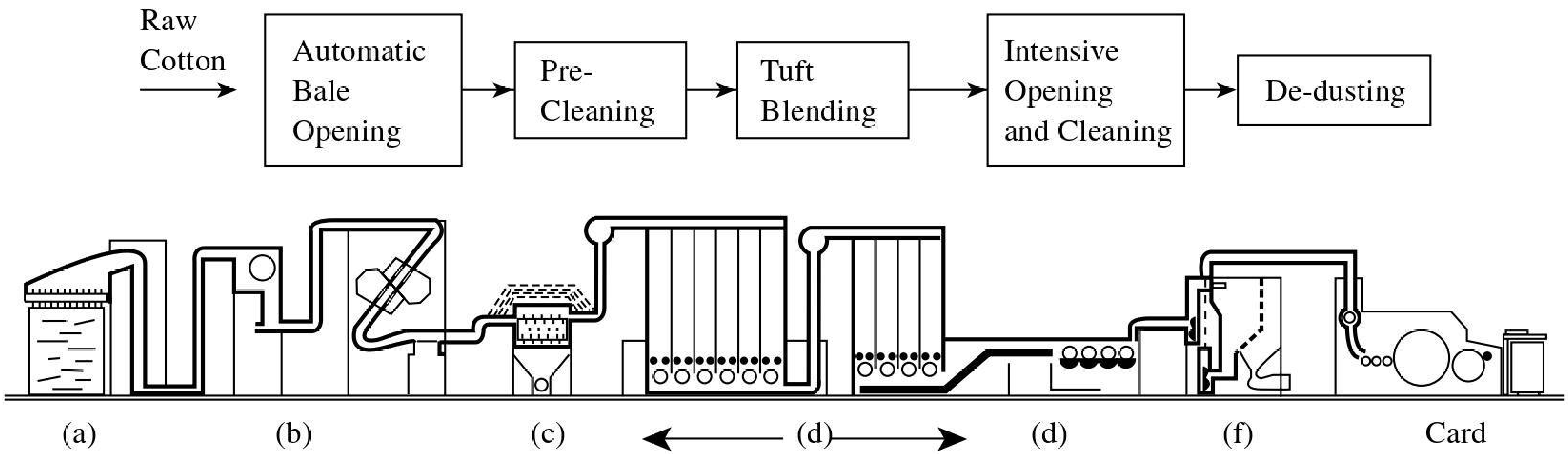


FIGURE 2.24 Example of blowroom sequence for cotton fibers. (Courtesy of Trutzschler GmbH.)

now has pressure and light sensors linked to a central computer control that monitors and regulates the pneumatic transport of material from machine to machine, thereby optimizing machine utilization. However, even with such sophistication, the overall cleaning efficiencies of blowroom installations fall within the range of 40 to 70%,[1,38] depending on fiber type.

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APPENDIX 2A

Lubricants

Lubricants are applied to wool for a number of reasons associated with the friction characteristics of the scoured wool, but principally to minimize fiber breakage and static charges resulting from frictional contact with machine components, and to facilitate cohesion of blends containing short fibers or lustrous fibers with low interfiber friction. The alleviation of such problems minimizes the generation of fly (airborne fiber fragments and short fibers) and the loss of good fiber during the material processing. Lubricants may also be used to disperse antistatic agents in the production of yarns for certain end uses, e.g., carpets. It is, however, axiomatic that, once a lubricant has fulfilled its function of facilitating processing, it should be easily removable, preferably with a biodegradable synthetic detergent.

There are three main types of lubricants: fatty, saponifiable oils, mineral oils, and synthetic lubricants.

Fatty-based products. This is the traditional product, which is declining in use. It comprises oleine (oleic acid obtained through a chemical treatment of fats) with an emulsifying additive, oxidation stabilizers, and antistatic agents. Fatty-type lubricants are saponifiable (i.e., will form soap in the presence of an alkali) and are easily removed in soap/alkali scouring solutions.

Mineral lubricants. These are refined mineral oils blended with surfactants. Although they are not water soluble, they do produce emulsions when mixed with water, and this ease of emulsification aids scourability.

Synthetic lubricants. These may be based on silicones, polyglycols, or synthetic esters and are either water soluble but grease immiscible, or water soluble and grease miscible. The latter is used when the yield has a high residual grease content (approx. 5%), as is usually the case for carpet yarn production.

The choice of lubricant usually dependents on the end use of the yarn, particularly with woolen spun yarns. Generally, the performance of fatty-based lubricants is favored by the knitwear sector, whereas, in the carpet sector, the trend has been to mineral-oil-based products and then to water-soluble lubricants. Reported studies of the range of lubricants on the worsted system show no preference as to lubricant type.[1]

Yarns are usually sold by weight and, ultimately, the lubricant applied to fibers will be part of the measured weight. To satisfy both the commercial implications and the technical requirements, the amount of lubricants applied is kept within 5 to 10% of actual oil, based on weight of fiber (WOF). This may be administered to the fiber in an emulsion form having equal amount of water. The water evaporates during processing, having assisted in evenly distributing the lubricant throughout the fiber mass. A low level of lubricant may be used for processing, referred to as *dry* processing, which must be carried out under high relative humidity of around 75% and 18°C. The wool should have a residual grease content of 0.3%. A mixture of 1% water-soluble lubricant and 6% water WOF is applied to the fiber blend to obtain a regain of 22%.

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