6 Separation/Sorting and Volume Reduction

6.1 Separation/Sorting

The term separation is interpreted as meaning separation of one class of materials from another, such as plastics from metals. Separation is performed either at the source by the generator or at a material(s) recovery facility (MRF) [1]. An MRF[1] is a solid waste management plant that uses a combination of equipment and manual labor to separate and densify recyclable materials in preparation for shipment to reprocessors or recyclers of the particular materials recovered. An MRF that is designed to process source separated/commingled dry recyclables is sometimes referred to as a "clean MRF," while an MRF that handles commingled wastes including decomposable solid organic matter is often called a "dirty MRF."

Once classes of materials have been separated from each other, sorting is also generally needed to separate the films by polymer type from mixed flexible packaging. Sorting is a crucial and often neglected step in the recycling process. Failure to sort the collected packaging into material streams that recyclers can use leads to downcycling, that is, the production of recycled material no longer suitable for its original application. Sorting is most commonly performed at MRFs. Some MRFs produce single polymer–type film grade from a large size separation stream, which is mostly composed of polyethylene bags; however, the technology and logistics are in their infancy [2].

One of the challenges MRFs face is contamination in the material they receive with metals, paper, and other plastics, all of which can negatively affect the final recycled product, for example, a single allen wrench carelessly thrown into a bale of film could wreak havoc if it passed through the metal detection equipment and made it into the reprocessing equipment undetected [3]. Most MRFs in the United States consider flexible plastic films as a contaminant because the films can easily get

[1] Also known as materia(s)l reclamation facility or material(s) recycling facility.

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tangled in sortation equipment at MRFs, causing the lines to shut down so that workers can remove the clogged (jammed) film [3].

For plastics that make up small percentages of incoming MRF materials or materials that require costly specialized equipment for sorting, sorting may be performed at plastic recovery facilities (PRFs). A PRF can be considered as a plastic-specific MRF. It is a facility where the mixed plastics are separated into different formats and/or polymers by manual, mechanical, and optical means (see Chapter 8). Currently, there are no PRFs for mixed types of plastic film in the United States. Once film has been sorted into market grades of compatible types, either by the generator or by MRFs/PRFs, it is sent to a reprocessor or recycler for cleaning and processing, followed by sale to end users that can use it as a raw material in recycled content product manufacturing [1].

The main technologies used for the separation and sorting of flexible plastic packaging are discussed in the following subsections.

6.1.1 Manual and Vacuum-Assisted Manual Sorting

In manual (or visual) sorting, targeted materials are removed by hand on the basis of shape, size, and/or color and redirected into storage bins. Manual sorting is the most widely used method to separate packaging films from a waste mixture in any size facility. Manual sorting is suitable when a large amount of a plastic packaging component is present, but it is a labor-intensive and costly process. The cost of manually sorting film in the United States is at least $150/ton, not including the cost that film adds to additional quality control (e.g., to remove stray film) from other product grades and the cost of removing film from screens [1]. Low labor costs in Asian countries make the manual sorting of packaging waste an attractive option [4].

In vacuum-assisted manual sorting, laborers lift flexible plastic packaging into a vacuum system positioned above the belt at picking stations and redirect other material into storage bins. Retrofitted large-scale MRFs commonly utilize overhead suction tubes at manual sort stations to collect and convey plastic film from multiple points in the MRF to one central point. Manual sorters snatch and lift plastic film to the suction tubes. The plastic film is pulled in by the suction and conveyed to a storage bin. Older or smaller facilities may manually pick out film at only one point in the MRF and drop it down a chute into a bin [5]. The vacuum-assisted manual sorting improves the recovery volume by 40% and the quality of flexible plastic packaging materials removed manually at picking stations. Although the vacuum-assisted manual sorting is more efficient than

Figure 6.1 The FilmVac System [7]. *Courtesy of Impact Air Systems.*

unassisted manual, the volume of material that can be handled by each sorter is limited [6].

Impact Air Systems developed the FilmVac System for collecting and conveying handpicked material, such as plastic film, during the manual sorting process [7]. The FilmVac System consists of a series of specially designed material collection hoods that are typically mounted in the ceiling of the sorting cabin above the waste belts (see Fig. 6.1). A series of collection hoods can be connected together via a range of ductwork, meaning all material is transported to a single point within the MRF, eliminating the need for transfer stations and additional storage bunkers.

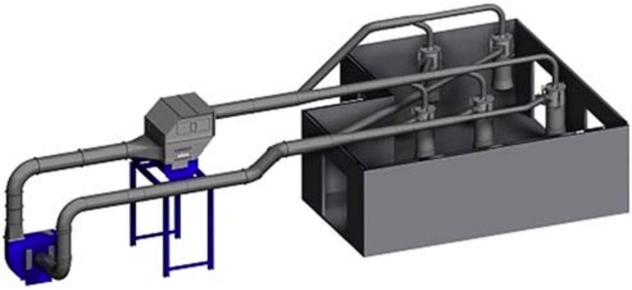

Figure 6.2 The Nihot Film Vacuum System (FVS) [8]. *Courtesy of NIHOT.*

Material is typically fed directly into a bale press or compacted in the so-called Impact Film Screw to reduce the film's volume (see Section 6.2.1).

For manually sorted plastic film, Nihot has developed the Film Vacuum System consisting of one or more suction points above a sorting belt, a recirculation fan, and a material/air separator. The complete system works in a closed loop (see Fig. 6.2). The film, which is manually brought to the suction point, is sucked into a suction hood and conveyed pneumatically to a rotary air separator, where the air and film are separated. The film is dropped pressure less into a baler, press container, bay, or onto a conveyor. The aspirated air is recirculated by the fan and led back to the opening of the suction point [9].

Manual sorting can promote the collection of all types of packaging films and sorting into more than one film grade. This could be achieved by adopting the following processing steps:

- separate film from no-film materials (the best practice for manually sorting film is for all film to be "bags-in-bags," i.e., all film stuffed inside a tied-off bag);
- open bags-in-bags so each piece of film is individualized;
- sort out bags and film that are only polyethylene into a one grade; and
- leave all remaining film as a mixed film/laminate grade [5].

6.1.2 Air Separators

An air separator removes light or heavy items from a waste stream. Other names used for an air separator are air classifier, wind sifter, wind shifter, or aeraulic separator. Using an airflow, the materials from one stream are separated into various streams depending on the size, shape, and weight of the waste items. An air separator is typically situated at the beginning of the waste material stream to preseparate the lighter material (plastic bags, plastic film, light packaging) from the heavier materials (plastic bottles, plastic containers, heavy objects). In modern systems, packaging films are presorted either by air separators (1- or 2-stage) or ballistic separators.

Several manufacturers, including Ken Mills Engineering (partner of Krause Manufacturing Inc., of the CP group), Bollegraaf, Nihot, Bezner (of the Heilig Group), Parini s.r.l, and Waste Sorting Line, build air separator systems, which can be used for the separation of packaging films.

Ken Mills Engineering developed the Air Drum Separator (ADS), which separates light flexible two-dimensional (2D) material from rigid three-dimensional (3D) material streams in any MRF [10]. ADS applies

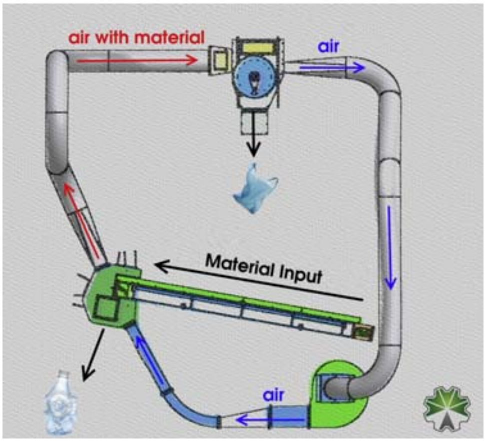

Figure 6.3 Schematic diagram of an aspirator air separator [11]. *Courtesy of PARINI S.R.L.*

vacuum technology through a rotating, perforated drum to draw the flexible 2D material against the drum, separating it from the rigid, 3D material that bounces off.

A schematic diagram of an air separator built by Parini s.r.l. is shown in Fig. 6.3. The input material to the air separator conveyed by a belt conveyor ends up in an extractor hood (black arrow or "material input"). Here, thanks to the controlled airflow generated by the fan (blue arrow or "air"), the light fraction is aspirated upwards and continues its path in a series of piping (red arrow or "air with material"), while the heavy fraction is discharged on a second conveyor. The light fraction then reaches the rotary valve, in which, thanks to the movement of the rotor and the consequent reduction of the air speed, the lightweight material is unloaded on another conveyor. The air then continues its path toward the fan, after which there is a dust suppression filter, thus closing the air recirculation.

DE9417627 U1 (1994, PAALS PACKPRESSEN FABRIK GMBH) discloses a system and a method, in which a waste stream of a material to be sorted is fed to an inclined sorting track constituted by a portion of a circulating, air-permeable conveyor member under which a vacuum is generated and maintained. Under the influence of the vacuum, flat material, such as plastic film and paper, adheres to the conveyor member and is entrained from the drop zone to the upper end of the sorting track. Other material, which is less susceptible to be held by suction through the air-permeable belt, such as bottles, cans, and other not generally flat material, does not adhere to the sorting track belt and descends to the lower end of the sorting track. Thus, plastic film and paper are sorted out of the waste stream.

Such a sorting step is of particular use in situations in which a dry waste consisting mainly of paper, metal, and plastic waste is collected in combination for efficient collection of waste. The flat material consists mainly of paper, and the plastic film can be sorted out of the paper in a separate sorting step, for instance, employing the apparatus disclosed in **EP1970130** (2008, MACHF BOLLEGRAAF APPINGEDAM B). However, a problem of such a sorting apparatus and method is that some nonflat materials are nevertheless entrained to the upper end of the sorting track, in particular, if waste is supplied at a high rate or irregularly so that high peak rates occur. This problem can to a large extent be solved by avoiding high waste supply rates, but this entails a reduced sorting capacity (2011, **EP2314387**, BOLLEGRAAF PATENTS AND BRANDS B V).

EP2314387 A1 (2011, BOLLEGRAAF PATENTS AND BRANDS B V) discloses a method and an apparatus, shown in Fig. 6.4, for sorting a flat material such as plastic film or paper from a stream of waste material, comprising a circulating air-permeable conveyor member (6) of which a portion constitutes a sorting track (7), extending and inclined from a lower end (8) to an upper end (9); means for maintaining a vacuum underneath the sorting track (11); and a motor (12) for driving the circulation of the conveyor member (6) in a sense of transport; wherein the sorting track (7) is arranged for entraining a portion of the material to be sorted with the conveyor member from a drop zone (15) of the sorting track (7) toward the upper end (9) of the sorting track and allowing another portion of the material to be sorted to descend from the drop zone (15) toward the lower end (8) of the sorting track (7) and further comprising a sweeper (2) between the drop zone (15) and the upper end (9) for sweeping flat material entrapping nonflat material off the entrapped nonflat material.

Most of the flat items (42) in the waste material (37) are engaged by the circulating conveyor belt (6) and transported upwardly from the drop zone (15); some of the flat items (42) may initially slide downwardly over some distance until being engaged by a portion of the sorting track (7) not covered by other material and then be transported upwardly toward the upper end (9) of the sorting track (7) and discharged into a flat item collecting bin (17). As at least most of the nonflat items (43) are not engaged by the circulating conveyor belt (6), at least most of the nonflat items (43) roll and slide from the drop zone (15) toward the lower end (8) of the sorting track (7) and drop into a nonflat item collecting bin (19).

Air separators offer multiple advantages to the sorting of plastic waste including: (1) effective separation of bulky plastic film waste from a two

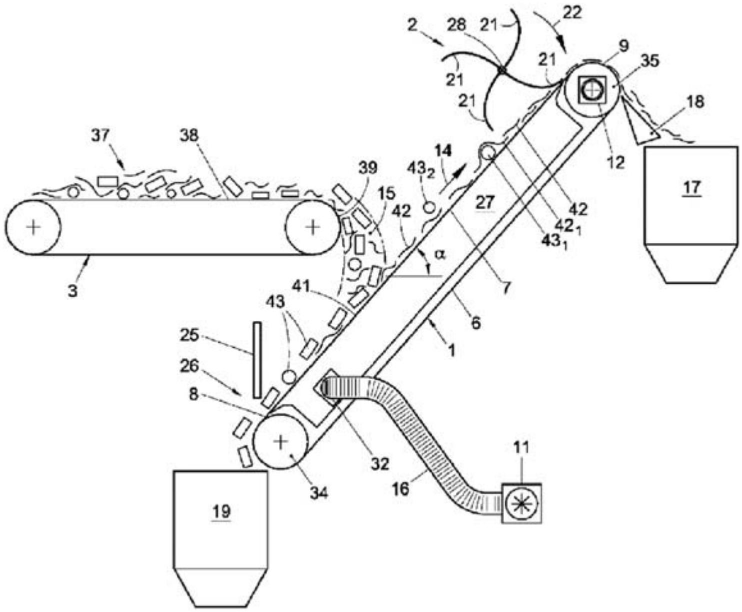

Figure 6.4 Schematic diagram of the apparatus for sorting flat material from a stream of waste (2011, **EP2314387** A1, BOLLEGRAAF PATENTS AND BRANDS B V). α, Angle; 1, Transport conveyor; 2, Sweeper in the form of a rotor; 3, Feeding conveyor; 6, Circulating conveyor member; 7, Conveyor sorting track; 8, Lower end of 7; 9, Upper end of 7; 11, Fan; 12, Motor; 14, Direction of transport; 15, Drop zone; 16, Air hose; 17, First discharge site; 18, Scraper; 19, Collecting bin; 21, Radially projecting flexible sweeping blades of 2; 22, Rotation; 25, Grader; 26, Drop zone; 27, Vacuum chamber; 28, Rotation axis; 32, Orifice; 34, Roller; 35, Roller; 37, Stream of waste material; 38, Feeding path; 39, Downstream end of 38; 41, Obliquely upwardly facing side; 42, Flat items; and 43, Nonflat items.

stream MRF; (2) reduction of wear parts; (3) the waste does not interact with the generator of the airflow, avoiding wear and clogging; (4) low maintenance; (5) high reliability and versatility (it can process very different waste streams); and (6) low dust emission [11].

The limitations of an air separator are: (1) it cannot distinguish plastic film from paper; (2) it cannot separate a polyethylene film from other polymer films or multilayers; (3) the separation of a film from a mixed containers stream would require quality control checking to produce film that meets recycling specifications [5]; and (4) when using the air separators with an optical sorter, the films do not stick well to the fast conveyor belts, and the jets of air used for separation have difficulty controlling the exit direction of the ejected flexible plastic. However, given the large range of size and shapes of flexible plastic packaging, several parallel processing lines and methods will likely be needed [12].

6.1.3 Screens

Screens are used to separate materials by size. The purpose of each screen is to agitate and spread out the material to break up loosely bound items and to separate smaller items from larger ones. There are four main types of screens: vibrating screens, trommel screens, disc screens, and ballistic screens. Some disc screens, as well as ballistic screens, are designed to screen small material as well as separate flat, 2D items such as film from 3D items such as plastic containers [13].

6.1.3.1 Ballistic Screens

A ballistic screen or separator is in many ways a combination of a vibrating screen with a disc screen. It has a small incline in the deck causing heavy materials to fall to the lower level of the deck, while lighter materials such as plastic films are transported upwards. Fine materials fall through the perforated bottom. A ballistic separator is a 2D−3D sorting apparatus and is used to separate rigid plastics (which tend to be three-dimensional) from plastics films, which are two-dimensional.

Ballistic separation is used to do three distinct separations: flexible materials, rigid materials, and to screen out a certain size fraction of material. Similar to a conventional disc screen, the 3D rigid items will tumble back, and the flat/flexible items will climb to the top front portion of the machine. Finally, the ballistic separator's paddles are fitted with replaceable screening plates that are used to screen out material of a certain size as determined by the application [14].

The ballistic separator has multiple advantages over a conventional rubber star screen.[2] The most appreciated benefit is certainly the lower operational cost of the machine. There are no rubber discs to wear out, and the elliptical movement does not result in the wrapping of long and stringy flexible items, which is what happens on the spinning shaft of a regular screen. Together, these two main aspects translate to more uptime with

[2] Named after star-shaped rubber discs located on the shafts.

lower, almost nonexistent, wear parts replacement and much lower labor costs related to cleaning the screen. Further, the ballistic separator has a compact footprint that makes it easy to integrate and retrofit within sorting systems, and it does a better and more constant job at separation than a regular star screen and also consumes less energy than a comparable capacity star screen [14].

6.1.4 Grabbers

Film grabbers (or grippers) are designed to capture plastic films and bags. The hooks (spokes, spikes, piercing needles, protruding fingers, or teeth) of a grabber pass very close to the conveyor belt to grab the films or bags and then retract and redirect them into bins. Large 3D objects must be removed before the grabber.

Patents **US4067506** A (1978, R.UTI.R s.r.l), **BE867777** A (1978), **US4207986** A(1980), and **BR7805346** A (1980) of SORAIN CECCHINI SPA disclose a series of apparatuses in which plastic films are separated from waste by bringing the waste in contact with circulating hooks that engage plastic films more than other waste materials brought in contact with the hooks. The circulating hooks displace engaged films away from other waste materials, and the engaged films are subsequently disengaged from the hooks and transported away for further processing and storage.

In particular, **US4067506** A (1978, R.UTI.R s.r.l) discloses an apparatus, shown in Fig. 6.5, for tearing open small bags containing city solid waste material and for separating out plastic film material and/or the bags,

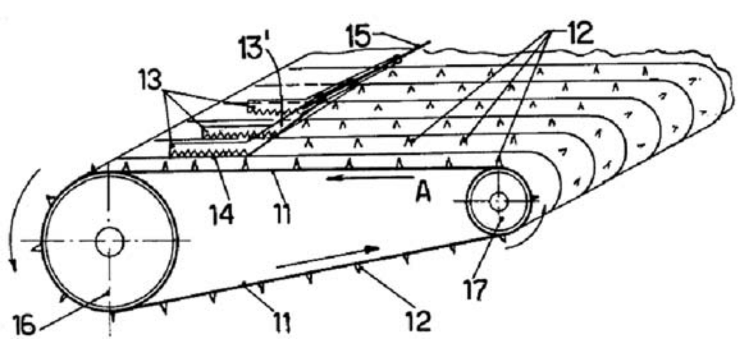

Figure 6.5 Schematic diagram of an apparatus for tearing small plastic bags (1978, **US4067506** A, R.UTI.R s.r.l). A, Direction; 11, Conveyor belt; 12, Hooks (aculei); 13, Blades; 13′, Hinges; 14, Blade's teeth; 15, Shaft; 16, Front transmission pulley; and 17, Rear transmission pulley.

comprising an endless conveyor belt (11), which carries on the surface thereof a plurality of hooks (or aculei) (12), which engage the bags placed on the surface of the conveyor belt (11). The belt follows a path of a first straight or rectilinear length and a second or return straight or rectilinear length. The transition between the first straight length and the second straight length follows a mild curve about a drive pulley having a relatively large diameter (16), whereas the transition between the return straight length and the first straight length follows a relatively sharp curve about a drive pulley having a relatively small diameter (17) so that such transition is sufficiently sudden; a plurality of toothed (serrated) blades (13) is pivotally carried on a shaft above the conveyor belt (11) so that the blades (13) are placed in proximity to the surface of the belt for engaging and tearing the bags carried thereon. Hook-like projections having a hook portion bent in a direction opposite to the direction of travel of the belt may be substituted for the hooks (12) for engaging the bags.

According to the invention, an important and essential feature of the apparatus is that the front transmission pulley (16) has a diameter that is substantially larger than the rear pulley (17). The difference between the diameter of the front pulley and the rear one, with respect to the direction of travel of the belt, is significant not only for the tearing of little bags but also for the other important workings of the apparatus. When the belt reaches the rear transmission roller (17) having a small diameter, about which the belt follows a relatively sharp curve, the plastic films that are being carried on the hooks, as a consequence of the sharp movement of the belt, will fall off so as to be conveniently collected.

BE867777 A (1978), **US4207986** A (1980), and **BR7805346** A (1980) of SORAIN CECCHINI SPA disclose an apparatus, shown in Fig. 6.6, for separating waste material (10) composed mainly of plastic film and paper including a conveyor belt (1) for moving the waste material along a substantially horizontal path in a given direction and a reel device (2) having a plurality of spokes or hooked members (11) extending therefrom rotating to move the spokes through the waste material at a portion of the horizontal path, with the spokes moving in the same direction in which the waste material is moving while being passed there through. The spokes of the reel device engage plastic film contained in the waste material to separate the plastic film therefrom. In another variation of the apparatus, the reel device (2) may be formed by a plurality of generally linear belt type conveyors each extending at an oblique angle to the horizontal direction of travel of the waste material and each having an end overlapping an adjacent reel device so that engaged plastic material may be serially deposited between reel devices in an upstream direction taken

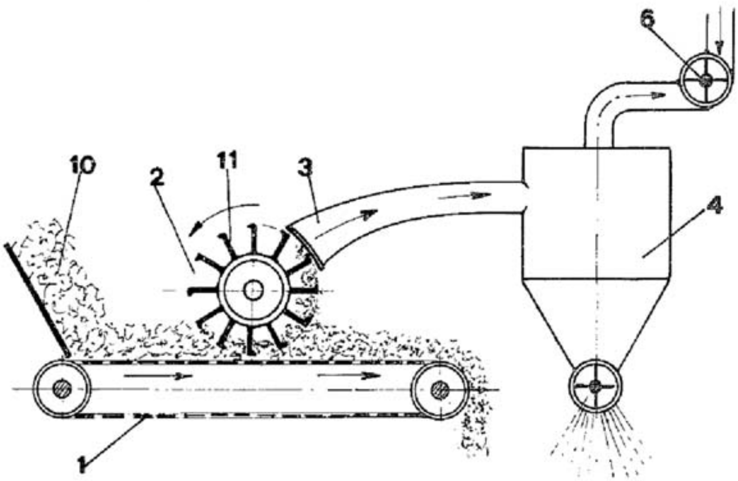

Figure 6.6 Schematic diagram of the separation apparatus (1978, **BE867777** A; 1980 **US4207986** A; 1980. **BR7805346** A of SORAIN CECCHINI SPA). 1, Conveyor belt; 2, Reel device; 3, Intake mouth; 4, Decanting or settling cyclone; 6, Fans; 10, Waste material; and 11, Spokes of the reel (2).

relative to the direction of travel of the composite material until it is removed from or released by the reel device that is furthest upstream.

JPS5422477 A (1979, NIPPON KOKAN KK) discloses an apparatus and a method for separating plastic films from paper, by piercing the plastic with a hole by heating and hooking and conveying the plastic with a hook. The apparatus, shown in Fig. 6.7, comprises: 1) a rotary drum (2) having a top inlet opening (4) and a bottom outlet (23); a series of electrode hooks (7) projecting from an inner surface of the drum and spaced from each other angularly; 2) a fixed semicircular electric current carrying rail connected to the electrodes; 3) a cooling air nozzle (17) arranged in the drum at the opposite side with reference to the electric current carrying rail; and 4) a conveyor belt (5) arranged in the drum (2) below a top end of the rail. Specifically, the electrodes are heated when they come into contact with the rail, so that they fuse the plastic waste and make a hole thereon to hang it upwards. During this lifting motion, electric current is stopped and cold air is blown from the nozzle (17). At the top, electric current reenters the electrodes to fuse the hole and then the plastic waste falls onto the conveyor belt.

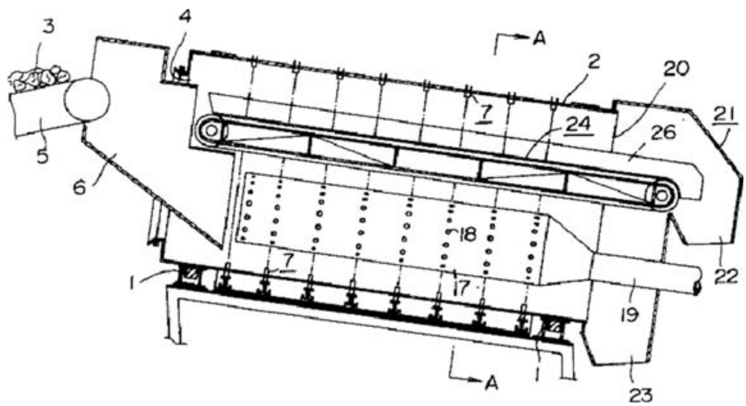

Figure 6.7 Apparatus for separating plastics from paper (1979, **JPS5422477** A, NIPPON KOKAN KK). A, Direction line; 1, Roller; 2, Rotary drum; 3, Waste mixture; 4, Top inlet; 5, Conveyor belt; 6, Chute; 7, Electrode hook; 17, Cooling air nozzle; 18, Holes; 19, Pipe; 20, Rotating cylinder; 21, Hood; 22, Plastic outlet; 23, Bottom outlet; 24, Plastic discharge conveyor; and 26, Skirt plate.

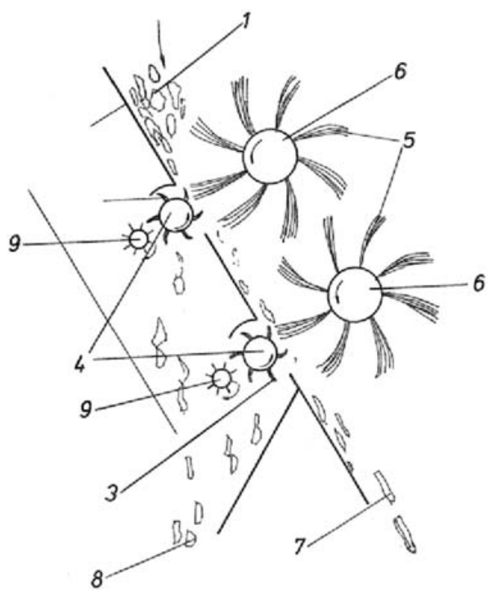

Figure 6.8 Schematic diagram of an apparatus for the sorting out of plastic film from a mixture of waste (1982, **EP0050259** A2, VOELSKOW PETER). 1, Mixture of waste; 3, Spikes; 4, Spiked roller; 5, Brush bands; 6, Brush rollers; 7, Remaining refuse; 8, Textile refuse; and 9, Combing-off rollers.

EP0050259 A2 (1982, VOELSKOW PETER) discloses a method and apparatus for the sorting out of plastic film from a mixture of waste from which heavy components, such as small pieces of stone, glass, and metal, have already been removed (see Fig. 6.8). The waste (1) descending in a thin layer is swept by the brushes (5) of a brush roller (6) onto sharp spikes (3) moving in the opposite direction; only those articles that have high tensile strength are spiked, whereas components with lower tensile strength such as paper are torn by the spikes (3) and are further conveyed by the brooms or brushes (5) together with the components that are not seized by the spikes, such as leather, cardboard, and wood, and which slide away across the spikes. Combing-off rollers (9), e.g. spiked rollers or brush rollers, may be used, rotating at higher velocity and in opposite direction to the spiked rollers (4), to loosen hanged plastic films from the spikes. Plastic film and any textile waste present are effectively removed by the spikes with a minimum amount of other accompanying materials, such as paper.

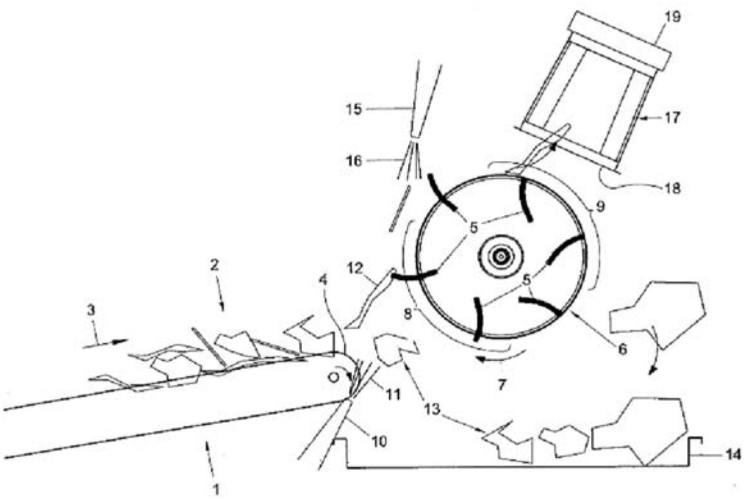

Figure 6.9 Schematic side view of the apparatus for separating plastic film from waste (2008, **EP1970130** A1; 2008, **US2008223770** A1, MACHF BOLLEGRAAF APPINGEDAM B). 1, Supply track; 2, Waste; 3, Supply direction (arrow); 4, Downstream end; 5, Hooks; 6, Drum; 7, Sense of circulation (arrow); 8, Engagement area; 9, Disengagement area; 10, Blower; 11, Upward airflow; 12, Fraction of the waste (2); 13, Remainder of the waste (2); 14, Discharge conveyor; 15, Blower; 16, Counter airflow; 17, Discharge channel; 18, Inlet; 19, and Ventilator.

EP1970130 A1 (2008) and **US2008223770** A1 (2008) of MACHF BOLLEGRAAF APPINGEDAM B disclose an apparatus, shown in Fig. 6.9, and a method for separating plastic film from waste (2) comprising a plurality of hooks (5) mounted on a drum (6) for circulating the hooks (5) along a trajectory through an engagement area (8) near a supply track (1) and through a disengagement area (9) downstream of the engagement area (8). The engagement area (8) is located higher than the supply track (1) and/or in supply direction (3) beyond the downstream end of the supply track (1), such that, in operation, a remainder of the waste (13) passes by the trajectory of the hooks (5) without contacting the hooks (5).

By an upward airflow (11) generated by a blower (10), a fraction (12) of the waste (2) that is easily entrained by the airflow, such as a flexible plastic film, is separated from the waste (2) and blown against the hooks (5) in the engagement area (8). The remainder of the waste (13), such as paper that is not engaged by the hooks (5) once it is outside the upward airflow (11), drops onto the discharge conveyor (14).

The hooks (5) project from the drum (6) via openings in the circumferential surface of the drum (6) and are retractable into a circumferential surface of the drum (6). Because the hooks (5) that are rotated along with the drum (6) are retracted, no separate members for stripping caught film material are required, and the construction can be relatively light and simple and is suitable for rotation at relatively high rotational speeds. Moreover, the openings in the drum via which the hooks project and retract only need to be small so that the inside of the drum can be well shielded from the waste material.

According to **FR3009211** A1 (2015, NEOS), the aforementioned separation apparatus is very sensitive to fine particles of waste, which will be driven by the airflow produced by the first nozzle and obstruct the drum. This requires to provide upstream of the separation apparatus a device for removing the fine particles from the waste stream, which increases the cost. Also, this separation apparatus does not enable the separation of the so-called "heavy" films, which are films that have been wrapped at least partially on other nonflexible solid waste or films in which solid waste is trapped. Another disadvantage of this separation apparatus is that it will be easily rendered inoperative in the event of aberrant waste in the waste stream, such as hard metal pieces. Indeed, the hooks will be bent by such aberrant waste and cannot be returned to their retracted position, forcing a stop of the separation apparatus and the entire sorting chain of which forms a part.

CN201760985 U (2011, WUXI CHANGJIANG MECHANICAL and ELECTRICAL CO LTD) discloses a flexible plastic film collecting device

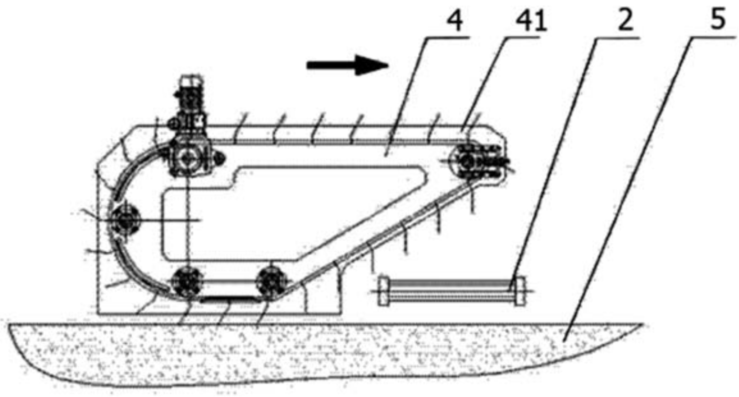

Figure 6.10 Schematic diagram of the flexible plastic film collecting device (2011, **CN201760985** U, WUXI CHANGJIANG MECHANICAL and ELECTRICAL CO LTD). 2, Aggregate conveyor belt; 4, Crochet hook (needle) conveying device; 5, Water channel; and 41, Conveying belt of 4.

of a water-sorting waste treatment apparatus, shown in Fig. 6.10, comprising a conveying water channel (5), a crochet needle (or hook) conveying device (4), and a material collecting and conveyor belt (2). The crochet needle conveying device (4) is used to hook the flexible plastic film on the water surface and is composed of a closed loop conveyor belt (41) with crochet needles on the surface and runs against water flow; the material collecting and conveyor belt (2) is arranged between the end of the conveyor belt and the water surface, and the conveying water channel (5) is particularly a nonstage water channel without level difference. Viewed from the side site, the circulating conveying belt (41) in the crochet needle conveying device (4) presents a trapezoid-similar structure. When the flexible plastic film floats on the water surface and flows from the left side of the conveying water channel (5) to the right side, it is picked up by the crochets of the conveyor belt (41) and transported to the aggregate conveyor belt terminal (2), whereon the film is dropped and carried away.

CN201816154 U (2011, HUBEI HEJIA ENVIRONMENT EQUIPMENT CO LTD) discloses a sorting apparatus, shown in Fig. 6.11, for separating flexible plastic in a household refuse treatment plant. The flexible plastic sorting apparatus comprises a rack (2), a driving device (8), a lower guide shaft (4), a rotating device (6), grabbing hooks (5), a lower baffle plate (1), nozzles (3), and an air source supply device (not shown). The driving device (8) and the lower guide shaft (4) are respectively

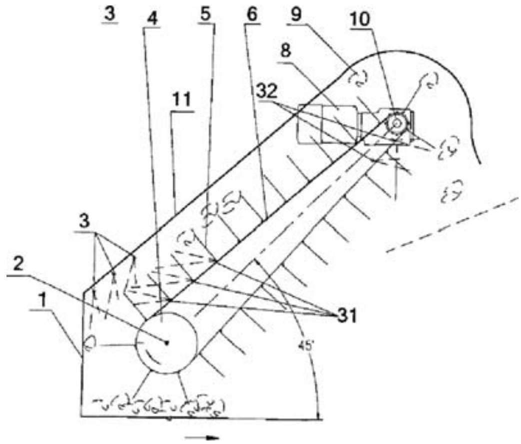

Figure 6.11 Schematic diagram of the flexible plastic sorting apparatus (2011, **CN201816154** U, HUBEI HEJIA ENVIRONMENT EQUIPMENT CO LTD). 1, Lower baffle plate; 2, Rack; 3, Nozzles; 4, Lower guide shaft; 5, Grabbing hooks (flukes); 6, Rotating device; 7, Air source connecting pipe; 8, Driving device; 9, Flexible plastic; 10, Drive spindle; 11, Outer cover; 31, Nozzles; and 32, Nozzles.

arranged on the rack (2); the rotating device (6) is arranged on the driving device (8) and the lower guide shaft (4); the driving device (8) drives the rotating device (6) to rotate; the rotating device (6) is provided with grabbing hooks (5); the lower baffle plate (1) is arranged on the rack (2) corresponding to the lower end of the rotating device (6); and a plurality of nozzles (3) is arranged and divided into three groups, two groups are respectively arranged on the rack (2) corresponding to the lower baffle plate (1), one group is arranged on the rack below the driving device (8), and the nozzles are respectively connected with an air source supply device. The flexible plastic sorting apparatus combines air separation with mechanical movement, and it is claimed to have the following advantages: improved efficiency of plastic sorting; less impurity in the recycled plastic; better quality of the recycled plastic; and economic and environmental benefits.

AT515429 A4 (2015) and **DE202015102117** U1 (2015) of HILLEBRAND JOSEF disclose an apparatus, shown in Fig. 6.12, for separating large plastic films and bags from mixed waste. The apparatus has an inclined supply surface comprising roller chains from which protrude pins (22), which revolve in a direction opposite to the slope of the supply surface, i.e., from bottom to top. Plates (25) are provided

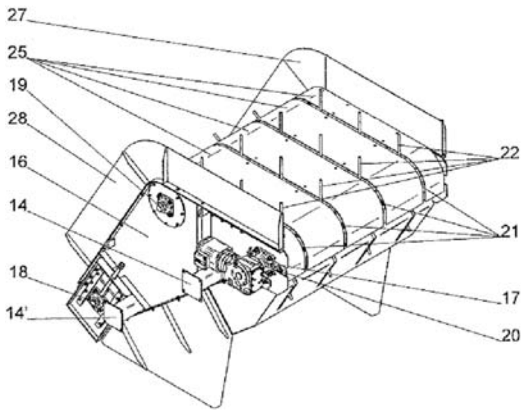

Figure 6.12 Schematic diagram of the separation apparatus (2015, **AT515429** A; 2015, **DE202015102117** U1 HILLEBRAND JOSEF). 14,14', Fittings; 16, Frame; 17, Drive shaft; 18, Clamping shaft; 19, Deflection shaft; 20, Motor; 21, Chains; 22, Pins; 25, Plates; and 27, 28 Lateral guides.

between the pins. The apparatus functions as follows: The waste to be separated is introduced to the first section. The waste slides down on the metal plates (25) but is plowed by the pins (22). Films larger than the distance between the chains (21) will stick to the pins (22) and will be carried up. The remaining waste slides down between the pins (22) and received by a conveyor belt. The guides (27, 28) prevent the material escaping sideways; the material can leave the apparatus only forward and backward. The inclination angle of the supply surface relative to the horizontal surface is 55–65°. The length of the pins is at least 250 mm.

FR3009211 A1 (2015, NEOS) discloses an apparatus (6), shown in Fig. 6.13, for separating films (4) from waste (2) moving in a supply conveyor (1) comprising retractable teeth (8); means for circulating the moving part along a path comprising a zone of gripping the films and a zone of disengaging the films (4) from the teeth (8); means for controlling the projection and retraction of the teeth so that, in the gripping zone, the teeth (8) are projected; and means for maintaining the teeth (8) in the projected position in the gripping zone, characterized in that the holding means comprise rigid support means secured to the teeth (8) and at least one rail (not shown) positioned such that when the teeth (8) are in the projected position, the rigid support means is in contact with at least one rail and prevents the teeth (8) from being retracted.

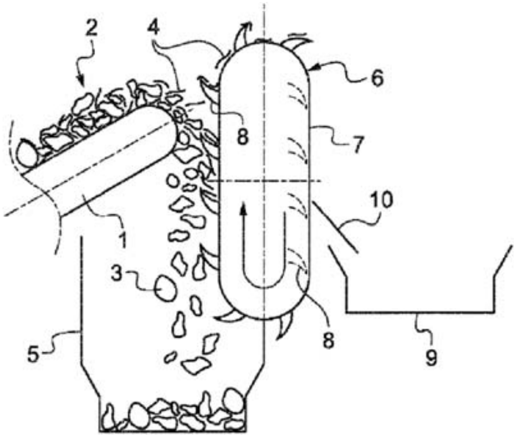

Figure 6.13 Schematic diagram of the separation apparatus placed at an end of a supply conveyer for pouring a mass of waste (2015, **FR3009211** A1, NEOS). 1, Supply conveyor; 2, Waste; 3, Various types of waste; 4, Films; 5, Bin; 6, Separation apparatus; 7, Circumferential surface of a drum; 8, Teeth; 9, Bin; and 10, Inclined baffle plate.

Film grabbers work well for individualized plastic bags and other very thin and highly flexible materials, but they are not effective in separating bags-in-bags or thicker polyethylene films and multilayer plastic packaging, and their effectiveness with films and bags is between 40 and 60% [6]. When this technology is used on a fiber or single-stream line, this system also captures some paper that would need to be manually separated later [5].

The base price of a film grabber is about $450,000, but with the addition of an air system, storage container, and installation costs, the total installed cost can be over $500,000 [5].

Reclay StewardEdge estimated the costs to sort curbside collected film from other recyclables using three different, commercially available MRF sorting technologies, namely manual sorting, air separator, and film grabber that could be considered under single- and dual-stream collection systems. Air separation had the lowest cost; however, output will likely be lower quality than other more costly methods [5].

6.1.5 Marking and Labeling Systems

6.1.5.1 Resin Identification Codes

The Resin Identification Code (RIC) system is a voluntary labeling system to allow consumers and recyclers to differentiate different types of

Table 6.1 Resin Identification Codes (RICs) for the Seven Most Commonly Used Resin Types According to ASTM D7611-13e1 [15]

Resin	Resin Indentification Code-Option A	Resin Indentification Code-Option B
Poly(ethylene terephthalate)	1 PETE	01 PET
High density polyethylene	2 HDPE	02 PE-HE
Poly(vinyl chloride)	3 V	03 PVC
Low density polyethylene	4 LDPE	04 PE-LD
Polypropylene	5 PP	05 PP
Polystyrene	6 PS	06 PS
Other resins	7 OTHER	07 O

plastics used in the manufacture of the product or packaging while providing manufacturers a consistent uniform coding system. The RIC system assigns each of the seven most common resins a number from 1 to 7, which is encircled by the recycle logo, a triangle of arrows (see Table 6.1). The code is molded, formed, or imprinted on all containers and bottles that are large enough to accept the 0.5 in minimum size symbol. The code is placed in an inconspicuous location on the manufactured article, such as the bottom or back, and is usually accompanied by the abbreviation symbol of the plastic.

Coding enables consumers to perform sorting before recycling, ensuring that the recycled plastic is as homogenous as possible to meet the needs of the end markets. Another potential benefit of coding is that it may facilitate the recovery of plastics not currently collected for recycling. The higher the recycling code number, the more difficult the plastic is to profitably be deployed into useful postconsumer applications other than by burning it for energy recovery or for disposal in landfills, which can create environmental problems. The RICs are used solely to identify the resin a plastic article is made of as detailed in ASTM D7611/D7611M-13e1 [15]. The RICs are not "recycle codes." The use of a RIC on a manufactured plastic article does not imply that the article is recycled or that there are systems in place to effectively process the article for reclamation or reuse. Their purpose is to assist recyclers with sorting the collected materials, but they do not necessarily mean that the product/ packaging can be recycled either through domestic curbside collection or industrial collections.

The RIC system is not considered accurate for the identification and (pre)sorting of packaging materials from a waste mixture. Further, the identification code on the surface of plastic moldings such as bottles or large plastic fragments that have been exposed for long periods to the sun or in the sea becomes often illegible as a result of erosion caused by sandblasting, wave action, and wind or UV degradation.

For plastic-based multilayers, the identification codes 81−90 are used. The identification codes of selected multilayers are presented in Table 6.2.

6.1.5.2 Marker Systems

Examples of environmental and recycling symbols include the universal recycling symbol (see Fig. 6.14) and the "Green Dot".

The universal recycling symbol is in the public domain and is not a trademark.

The Green Dot (German: Der Grüne Punkt) is the license symbol of a European network of industry-funded systems for recycling the packaging materials of consumer goods [16]. The logo is trademark protected worldwide. The "Green Dot" on packaging means that for such packaging, a financial contribution has been paid to a national packaging recovery company that has been set up in accordance with the principles defined in European Directive 94/62/EC and its national law. The logo informs the consumer that the manufacturer of the product contributes to the cost of recovery and recycling. This can be with household waste collected by the authorities (e.g., in special bags or in containers in public places such as car parks and outside supermarkets). The Green Dot logo

Table 6.2 Resin Identification Codes (RICs) for Selected Multilayers

Symbol	Description	Exemplary Uses
	Paper + PET	Consumer packaging, pet food bags, cold store grocery bags, ice-cream containers
	Paper and cardboard/plastic/ aluminium	Liquid storage containers, juice boxes, cardboard cans, cigarette pack liners, gum wrappers
	LDPE/aluminium	Food packaging

indicates that a company has joined the Green Dot scheme, and not necessarily that the package is fully recyclable.

6.1.5.3 Other Marking/Labeling Schemes

The How2Recycle label, shown in Fig. 6.15, is a voluntary standardized labeling system on packaging that clearly communicates recycling

Figure 6.14 The universal recycling symbol.

instructions to the consumer. It involves a coalition of forward thinking brands that want their packaging to be recycled and are empowering consumers through smart packaging labels [17]. The How2Recycle label provides information for the identification of the packaging material (plastic), and the packaging parts (bags/film/wrap) need to be recycled.

Another innovative solution for advanced sorting is digital watermarking, which could allow much better sorting and traceability of materials, with few retrofitting costs [18]. Radio frequency identification tags implemented in packaging products will also cause new challenges

Figure 6.15 The How2Recycle label [17]. *From How2Recycle®.*

for the waste management of plastics in the future [19]; see also Chapter 11, Section 11.4.3.

6.1.6 Optical Sorters

The two main optical (spectroscopic) sorting technologies are visible light (VIS) [3] sorting and near-infrared (NIR)[4] sorting. Visible light sorting uses a high-speed camera or other light sensor, equipped with a visible range spectrometer to detect different plastic items. It does not identify plastics by chemical nature. NIR sorting uses the wavelength fingerprint in the NIR region of specific polymers to distinguish from one another. It does not distinguish colored and multilayer packaging materials. NIR sorting is used in both MRFs and PRFs. The most common and widely used optical sorter is a device that combines visible light and NIR to detect plastics. With this optical sorter, the spectrum of light is reflected off the plastic surface to identify polymer type and color and then the components are sorted, often by plastic grade.

A representative patent for the sorting of packaging materials is **WO0138012** A2 (2001, DER GRUENE PUNKT DUALES SYST), which discloses a method and an apparatus for automatically sorting films, e.g., packaging films, equipped with an NIR device (see Fig. 6.16). The films are conveyed through a 3D measuring zone (26) of an NIR device (20) in an air stream (L) at a known flow velocity and are identified. The films are removed from the air current at a site different from that of the measuring device according to the nature of the identified material. The films can be made of polyethylene or polypropylene.

The main limitations of optical sorters can be summarized as follows:

- optical sorters can only be applied to monomaterials. However, most flexible plastic packages are made of many different materials;
- optical sorters scan only the material at the surface layer (ignoring deeper materials within a multilayer composite);
- there is no optical sorter system that could identify multiple, specific materials or their location on a conveyor belt;
- materials must be physically separated before they are scanned;
- optical sorters require their own special belts;

[3] Visible light refers to a wavelength spectrum in a range between 380 and 740 nm.
[4] NIR refers to a wavelength spectrum in a range between 760 and 2500 nm.

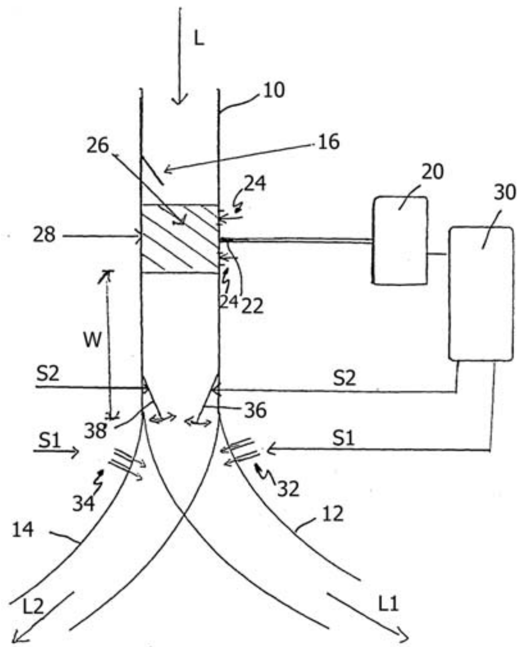

Figure 6.16 Schematic representation of a plastic film sorting apparatus equipped with a near-infrared (NIR) device (2001, **WO0138012** A2, DER GRUENE PUNKT DUALES SYST). L, Air stream; L1, L2, Partial air streams; S1, S2, Control lines; W, Short distance; 10, Wind tunnel; 12, 14, Removal tunnels; 20, NIR device; 22, Sensor; 24, While light; 26, 3D measuring zone; 28, Reflecting tube; 30, Control device; 32, 34, Blow nozzles; and 36, 38, Baffles.

- optical sorters cannot identify black colored films;
- as plastic films have a very low surface weight, sorting with optical sensors on acceleration belts is often inefficient;
- most types of optical sorters are unable to adequately distinguish material types when they have highly glossy, dark colored surfaces, paints, and coatings [12,20].

Another issue is created by the full wrap sleeve labels, which tend to obscure the automated detection systems during the sorting process. As a result, PET recycling facilities have seen decreasing yields as sleeved bottles tend to end up being separated from clear PET containers and discarded (see also Chapter 4, Section 4.2.5).

6.1.6.1 Fluorescent Light

Fluorescent additives have been used for the identification and separation of various polymers from a plastic waste. Dyes in the plastic to be sorted are excited by an irradiation source producing scattered emitted light that is intercepted by a detector and recorded.

Machine-readable inks (including fluorescent pigments) have shown great potential for the identification and separation of plastic packaging. Unlike NIR sorting practices, these technologies are not polymer specific and could be applied to targeted streams such as food contact plastic packaging, using commercial labeling and decoration methods and sorted using MRF infrastructure with only minor modifications [21].

A method of marking plastics consists of applying a lacquer, containing fluorescent markers, on a surface of a plastic packaging in the final step of its production [21]. In this method, it is also possible to apply the lacquer on labels. A nitrocellulose lacquer, with addition of organic and inorganic markers, is used as a coating. This method allows for efficient macrosorting of waste, but there is no possibility of sorting flakes. A weakness of this method is the lack of possibility to mark plastics before they are thermoformed. It is also necessary to use UV stabilizers due to marker aging. Because of the use of large concentrations of markers in the lacquer, in the range of 0.5−5%, and the use of expensive inorganic markers containing rare earth metals, the described method is costly (2018, **WO2018182437** A1, ERGIS S A; INNOVALAB SP Z O O).

Fluorescent markers as plastics recycling aids have been widely reported in the patent literature. Some recent patents on the fluorescent marking and sorting of plastic packaging waste are presented below.

WO2018182437 A1 (2018, ERGIS S A; INNOVALAB SP Z O O) discloses components of a system for marking plastics with fluorescent additives and their application in identification and sorting of plastic waste, including waste of multilayer and multicomponent plastics, using the fluorescent radiation emitted by plastic item after its excitation. The coating material for marking plastics contains a base and fluorescent markers dissolved or dispersed and also in a form chemically immobilized on a spherical polymer matrix with a diameter below 2 μm, in the base of the coating material. The base of the coating material can be an aqueous dispersion of appropriate resins (e.g., acrylic, alkyd, silicones) or it can contain ethyl acetate, 2-(2-butoxyethanol), 2-butanone, and their mixtures. The coating composition or the way it is printed constitutes an arbitrary code, consistent with the adopted marking system. The coating material can be washed off from the surface of marked material with a washing agent. Alternatively, the coating material can be fixed to the surface of plastics. The code contained in the composition of the coating material or in the way it is printed is readable after irradiating with appropriate wavelength. The use of printed graphic or text patterns with at least two coating materials containing different fluorescent markers allows the creation of a practically unlimited number of individual identification codes. The proposed technology claims be able to sort multilayer materials into appropriate clean streams of various types of plastics, suitable for later reprocessing, and is complementary with other technologies, used at present on the market, for separating individual layers of multilayer material.

Some polymers such as poly(vinyl chloride) (PVC) fluoresce under black light and an enclosed black light manual sorting station can be used to separate out PVC and other polymers that fluoresce from either a polyethylene stream or a stream of film to be sent for recovery. Because polymers such as polypropylene, PET, or poly(lactic acid) (PLA) do not fluoresce naturally, manual sorting under black light is not effective for separating those polymers from polyethylene or each other.

DE102017118601 A1 (2019, TAILORLUX GMBH) discloses a sorting method for packaging materials comprising a base material and a marking material that absorbs and/or emits infrared radiation, preferably NIR. The method is particularly suitable for the separation of polyethylene film from an ethylene vinyl alcohol (EVOH) barrier film. The marking material is preferably a luminescent organic, inorganic, and/or organometallic dye, a pigment, and/or a complex compound. The luminescent marking material can emit radiation with a wavelength deviating from the excitation radiation, wherein the excitation radiation has a wavelength preferably in the UV, VIS, or infrared range, while the emission radiation has a wavelength preferably lying in the infrared range. The marking material is partially destroyed and/or removed before or during the processing step. The sorting method comprises the steps of irradiating the unsorted packaging material with electromagnetic irradiation; recording and analyzing the emission and/or absorption spectra with a defined wavelength range;

identifying and separating packaging materials provided with the marking material; and processing the separated packaging materials.

6.1.7 Robotic Sorters

The robotic sorter is a promising technology that could assist and eventually replace optical sorters in the detection and separation of specific materials. Currently, several companies are testing proprietary robotic sorters in MRFs for the sorting of flexible packaging films from commingled waste streams.

AMP[5] Robotics, a start-up company founded in 2015 by Matanya Horowitz, has developed a robotic system that can rapidly pick recyclable materials off a conveyor belt for recovery [22]. The robotic system, called the AMP Cortex Robotic Sorter, comes with Neuron the artificial intelligence that peers into the recyclable stream to identify individual pieces of recoverable material in piled, mixed waste. The Neuron software transforms the material on the recovery belt into valuable data using computer vision to distinguish features in much the same way as the human eye (see Fig. 6.17B). The AMP's system can figure out different combinations of features—for instance, shapes and the specific shininess of aluminum. Features of new materials are added to the learning algorithms of Neuron. The robotic system shows the potential to be able to identify virtually any item it has yet to encounter. Once the APM's robot moved from the lab and put to the test in MRFs, there were hurdles to overcome. A big one was improving the ability to grip a wide variety of materials, which is still being fine-tuned.

AMP's robotic system is claimed to have the following advantages:

- cuts sorting costs by 50%;
- stabilizes labor spend by fixing labor rate for sorting stations, while lowering labor needs;
- exceeds the return on investment offered by legacy recycling equipment;
- designed to detect and separate multiple materials;
- improves bale quality by reducing contamination levels;
- can be installed with practically no retrofit on existing conveyor belts; and

[5] "AMP" stands for autonomous manipulation and perception.

- provides higher throughput yields greater recovery rates and more revenue.

Some of the disadvantages of the APM's robotic technology are:

- technology is not yet mature and more testing is needed in the real-word conditions of an MRF; and
- need to improve the ability to grip a wide variety of materials, which is still being fine-tuned.

EP1829621 A1 (2007) and **US2007208455** A1 (2007) of MACHINEFABRIEK BOLLEGRAAF APPINGEDAM B.V. disclose a sorting system (see Fig. 6.17) for extracting recyclable items from waste material comprising a conveyor (4) for transporting waste material (6); a detector (8) for identifying and locating items of the waste material (6) on the conveyor (4); depositing openings (11, 12, 14, 15, 17) along the conveyor (4); eight robots (1.1−1.8) along the conveyor (4); and a control circuitry (32) that is equipped with a central control unit (41) that communicates with the detector (8) and the robot motors. Each robot has arms (34, 35, 39) driven by corresponding motors. The central control unit (41) determines control signals for the motors from signal obtained from the detector.

Bollegraaf's robotic system has been testing for the sorting of flexible plastic packaging out of waste material.

The design application of this technology is for quality control sorting and for production sorting in low- to medium-throughput applications. Units developed so far consist of an optical scanner over a conveyor belt followed by a robotic arm that picks low percentage contaminants from a conveyor and deposits them into a bin, chute, or onto another conveyor [5].

Compared to manual sorting at 50 picks per minute, a robot arm can make over 200 picks per minute. A single scanner can support multiple arms on a single conveyor, so theoretically, rates of over 1000 picks per minute are possible. Also, robot arms have the capability of picking items that overlap other items, something that air separators and optical sorters that use air jets for sorting cannot do well. Another advantage of robot sorters is the potential to sort multiple products with a single-robot system. As applied to plastic film, the limitations will be throughput

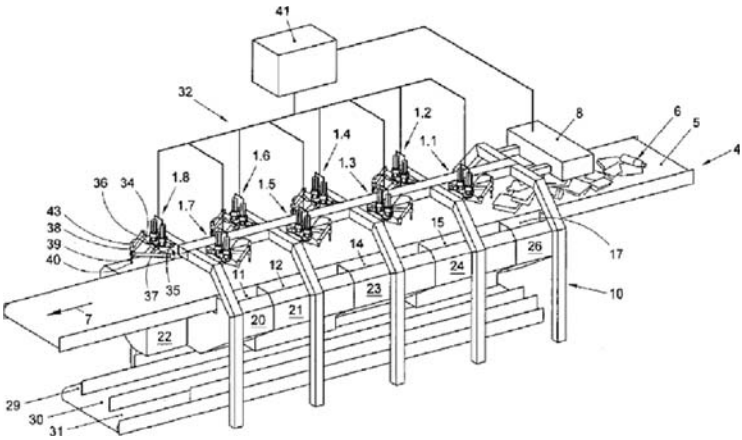

Figure 6.17 Robotic system for sorting items out of waste material (2007, **EP1829621** A1; and **US2007208455** A1, MACHINEFABRIEK BOLLEGRAAF APPINGEDAM B.V.). 1.1–1.8, Eight robots; 4, Conveyor; 5, Conveyor track; 6, Waste material; 7, Transport direction; 8, Detector unit; 10, Frame; 11, 12, 14, 15, and 17 Depositing openings; 20, 21, 23, 24, and 26, Chutes; 29, 31, Outer tracks; 30, Central track; 32, Control circuitry; 34, 35, 39, Robot arms; 36, 37, Hinged carrier bags; 38, Linear motor; 40, Gripper; 41, Central control unit; and 43, Valve.

(because of the low weight of each pick) and sufficient discrimination between products.

According to Reclay StewardEdge [5], a robot sorter with a single sorting arm is estimated to cost less than an air jet optical sorter (about $400,000 installed), but until commercial production units are available, pricing remains uncertain. Additionally, operational costs are very uncertain, not knowing the true efficiency of a unit in sorting film in an MRF environment. Based on 100 picks per minute and the above capital costs, the range of allocated capital and operating costs may prove to range from $250–$400 per ton once this future technology is commercialized. However, it could also be significantly higher if the system cannot accurately handle bags-in-bags, if the burden depth is deep or if manual quality control after the machines is still required [5].

6.1.8 Eddy Current Separators

An eddy current separator (ESC) is used to remove nonferrous metals such as aluminum, brass, and copper from the waste stream. The material is separated in an ECS on the basis of eddy currents being generated in nonferrous materials by rapidly rotating permanent magnets. These eddy currents in turn cause the material to be repulsed by the magnet field of the ECS, and the nonferrous material is diverted from the waste stream and is ejected into a separate hopper or conveyor. Trials have demonstrated that ECS is effective at separating a significant proportion of multilayer packaging from the waste stream, alongside other nonferrous materials such as aluminum used beverage cans (UBCs) and aluminum foil [23]. ECS has been used in combination with other separating devices such as ballistic or angled disc screen separator and optical systems for the separation of plastic films and/or paper from other recyclables (2017, **US9713812** B1; **US2017253891** A1, ORGANIC ENERGY CORP). It has been proposed to use ECS as an additional separating device in the processing line of an MRF for the separation of pouches from the waste stream [24].

6.2 Volume Reduction

A problem with flexible plastic packaging waste is that it is bulky and takes up a large amount of space if left unprocessed. Volume reduction processes involve the transformation of this type of waste (including printed films and bags, coextruded barrier films, metalized films, and the like) into high bulk density products that can be easily handled or stacked. High bulk density products can be transported more efficiently to recycling facilities.

6.2.1 Compacting

Compactors are used to reduce the volume of flexible plastic packaging waste. Compactors reduce operating and housekeeping costs and can be located close to any process area.

A known type of compactor, typically referred to as a hydraulic compactor, is disclosed in **WO9407688** A1 (1994, MARSHALL SPV LTD). The compactor comprises a rotating shaft having a screw vane located in a conical chamber, wherein the waste material is driven through the chamber by the rotating shaft and is deformed and compressed before finally being discharged through a nozzle. Hydraulic compactors are generally slow in operation, and the compacted material can create dust and other airborne or surface waste pollution (2008, **WO2008135757** A1, TAYLOR PRODUCTS LTD). **US5452492** A (1995, HAMILTON ROBIN) discloses an alternative compaction method and apparatus, which utilizes a compaction chamber and a vane for conveying the waste material through the passage and includes an exit nozzle, which defines an internal transverse cross-sectional area that enlarges and reduces respectively in response to increasing and decreasing material pressure. Effectively, a plurality of fingers is provided at the outlet to control the size of the extrudate. However, such an apparatus puts severe force and stresses in the shaft and, furthermore, the waste reexpands once it is passed through the nozzle (2008, **WO2008135757** A1, TAYLOR PRODUCTS LTD; 2012, **WO2012035308** A2, MASSMELT LTD).

Compactors should not be confused with extrusion devices, which force a uniform homogeneous feedstock into alignment guides and specifically shaped dies to produce lengths of stock cross-sectional shapes, such as polymer pipes, rods or tracks. Extrusion machines are constructed similarly to the compacting apparatus mentioned above, except that they are only designed to handle throughput of a constant and consistent plastic material, and they are not compactors as such (2008, **WO2008135757** A1, TAYLOR PRODUCTS LTD).

DE4140577 A1 (1992, PAVEL WILFRIED MASCHINENBAU) discloses an apparatus for compacting used plastic films and/or plastic film waste into blocks designed as a mobile compactor. The compacted plastic film takes during transport only a relatively small space. Sources of scrap film are packaging films such as garments' plastic protective covers. However, because of air pockets often trapped between the films and the air-filled nubs in the films, compressing the films into a compact block requires a relatively large amount of time and energy (2003, **DE20308945** U1, PAVEL WILFRIED).

Impact Air Systems developed the Film Screw Compactor System to compress waste materials collected by the company's Filmvac System into manageable plastic [25] (see Section 6.1.1). The unit comprises a single screw auger within trough, which compacts the material into a circular outlet spigot. The unit achieves its compaction by means of combination of the length of the outlet spigot and the rubber tension clamping ring, which retains the expanding spool of plastic waste bag to provide a variable length sausage-like bale for ease of handling (see Fig. 6.18).

Figure 6.18 Sausage-like bale obtained by the Film Screw Compactor [25]. *Courtesy of Impact Air Systems.*

6.2.2 Softening or Melting the Outer Surface of Compacted Waste

DE2261678 A1 (1973) and **CH557763** A (1975) of FLUMS AG MASCHF disclose an apparatus, shown in Fig. 6.19, for compacting scrap wrapping film by feeding film trims into a compressing chamber having a funnel-shaped outlet end whose walls are heated with electrical heaters to a temperature sufficient to fuse together those trims coming into contact with the walls. A piston ram operating at regular intervals compresses the film trims into a compact mass, which is discharged from the outlet in the form of a continuous sausage having an outer skin formed from the fused film trims. The apparatus is designed to operate in conjunction with a packing station, where the plastic wrapping film is welded and trimmed.

FR2294037 A1 (1976, ALDES ATEL LYONNAIS EMBOUTISSA) discloses a method for compacting scrap film into a shaped block comprising compacted material enclosed in a shaped skin of heat shrunk and chilled material. The method is carried out in the apparatus shown in Fig. 6.20, wherein a container (2) for receiving the plastic waste to be processed into a block comprises a horizontally arranged tubular chamber (3), which on both sides is provided with pistons, of which one piston (7) is connected with a guide system (8) and a spring mechanism (10), whereas the other piston (5) is connected with a hydraulic jack (6). The chamber walls are heated and the walls and pistons have passages for circulating coolant. The cooling of the plastic waste to be compressed into a block occurs by means of a coolant, which is run through canals positioned in the walls of the tubular chamber and/or of the pistons. The load opening and

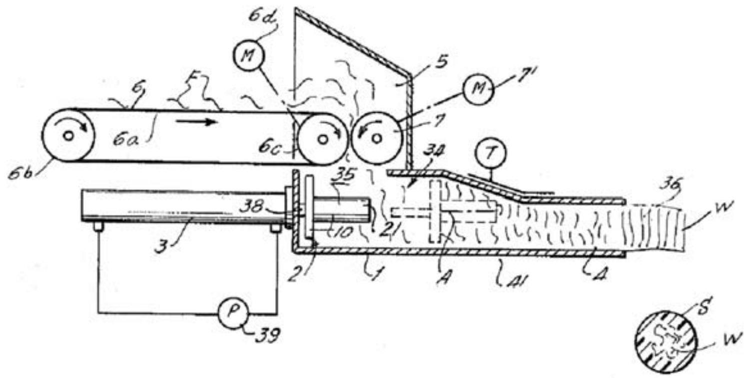

Figure 6.19 Cross-sectional view of the compacting apparatus (1973, **DE2261678** FLUMS AG MASCHF). A, Axis; IA, Line; M, Scraps of polyethylene film; S, Sheath; T, Thermostat; W, Compact sausage-like body; 1, Housing/compressing cylinder; 2, Ram/compressing piston; 3, Hydraulic cylinder/drive; 4, Funnel; 5, Feed casing; 6, Conveyor belt; 6a, Horizontal transport belt; 6b, 6c, Rolls; 6d, Electric motor; 7, Feed rollers; 7′, Electric motor; 10 Circular disc; 21, Cylindrical plunger/projection; 34, Chamber; 35, Inlet; 36, Outlet; 38, Piston rod; 39, Pump; and 41, Heater.

discharge opening (4) are the same. The apparatus is suitable for compacting scrap film, especially polyethylene film, for recovery and reuse; it increases the material bulk density for economic transport without causing mechanical or thermal degradation of the molecular structure.

According to **EP0397280** A1 (1990, PWR RECYCLING BV), the aforementioned apparatus has the disadvantage that the processing of the plastic waste into a block is very complicated and, therefore, expensive. The walls of the tubular chamber as well as the inner surfaces of the pistons are not provided with a coating resulting in the adhering of the obtained plastic waste blocks to the walls, with the consequence that on the one hand, the removal of the blocks is difficult, and on the other hand, the walls have to be cleaned repeatedly. The apparatus has also the disadvantage that the plastic waste may get stuck easily during compressing. Further, the plastic waste to be compacted is transported by means of a piston to a funnel-like device, which is open at its tapered end, so that subsequent to heating and compacting, the material leaves the apparatus in the form of a continuous sausage, i.e., no blocks are obtained.

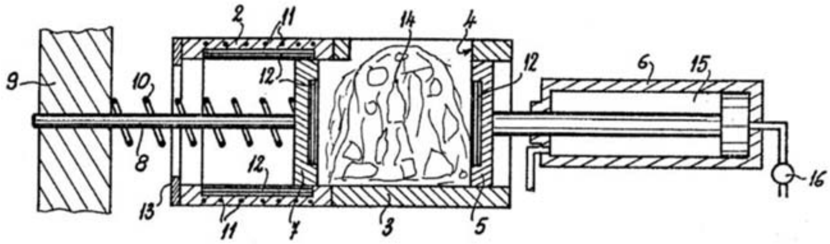

Figure 6.20 Apparatus for compacting thermoplastic sheet or film (1976, **FR2294037** A1, ALDES ATEL LYONNAIS EMBOUTISSA). 2, Container; 3, Tubular chamber; 4, Opening (load and discharge); 5, Piston; 6, Hydraulic jack; 7, Piston; 8, Guide system/rod; 9, Fixed support; 10, Helical spring; 11, Heating plugs; 12, Circuit for the circulation coolant; 13, Stopper; 14, Plastic materials; 15, Chamber of 6; and 16, Pressure regulator.

EP0397280 A1 (1990, PWR RECYCLING BV) and **US5263841** A (1993, THERMOPERS BV) disclose a method and an apparatus, shown in Fig. 6.21, for compacting plastic waste into blocks claiming to overcome the aforementioned problems. Plastic waste, such as packaging film of PVC, polyethylene, or polypropylene, is introduced into a container and compressed, whereas the walls and bottom of the container are heated by means of electrical heating elements to soften the surface of the plastic waste, followed by cooling, wherein the outer layer solidifies and the obtained compressed block-like plastic waste is removed. The compressing of the plastic waste takes place by means of a punch at a temperature of 120−180°C (preferably, 140−160°C) and a pressure of 250−400 g/cm^2 (preferably 260−290 g/cm^2), followed by cooling by introducing air in the container with a fan for 5−15 min (preferably 8−10 min). The inner surfaces of the container and/or the punch are provided with a coating (e.g., of Teflon) to prevent the softened and compressed plastic waste from adhering to the walls.

Although the aforementioned method and apparatus are able to achieve a substantial volume reduction of the plastic waste film, both are too laborious in industrial or semiindustrial scale. In particular, in the claimed apparatus, the plastic waste must be loaded and unloaded manually. This not only disturbs the throughput of plastic waste but also renders the apparatus less suitable for the processing of contaminated plastic waste (1997, **NL1002391** C2, ICORDE).

US3831340 A (1993, TULKOFF M) discloses a method for compacting a scrap film being bulky due to incorporation of air pockets of air.

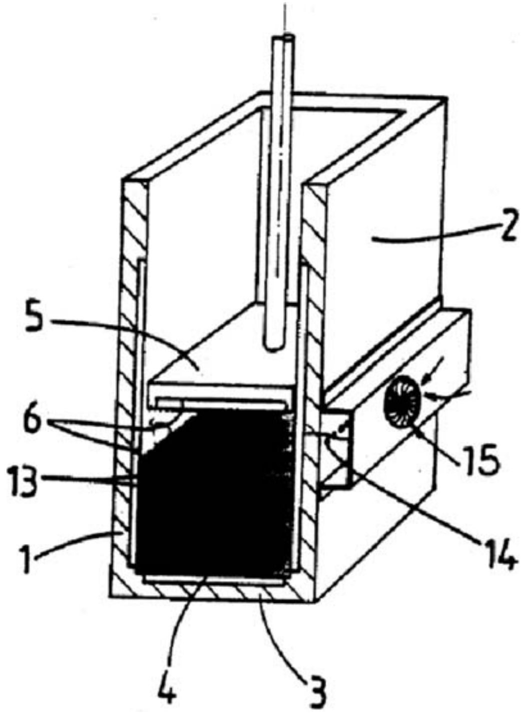

Figure 6.21 Apparatus for compacting plastic waste (1993, **US5263841** A, THERMOPERS BV). 1, 2, Side walls; 3, Bottom wall; 4, Plastic waste load; 5, Punch; 6, Heating elements; 13, Teflon coating; 14, Orifices; and 15, Air fan.

The scrap film is oftentimes in the form of thermoplastic bags of fairly heavy gauge and large size. The bag is used to enclose a stack of a plurality of boxes that have been positioned on a pallet. The bulky film is loaded into a receptacle of relatively large size, shown in Fig. 6.22, having a plurality of openings along all of its surfaces. The receptacle is then subjected to a heat treatment at a temperature of at least 240°F (116°C) in an oven that surrounds the receptacle along its sides and top, while the receptacle is on the floor. The oven employed is essentially a housing having an open bottom with a plurality of electric heating elements positioned internally with respect to the inner walls thereof. The oven is relatively movable to encompass the bag containing receptacle. The bags are melted or fused within the receptacle during its dwell time in the confines of the oven. To prevent sticking of the bags to any of the surfaces

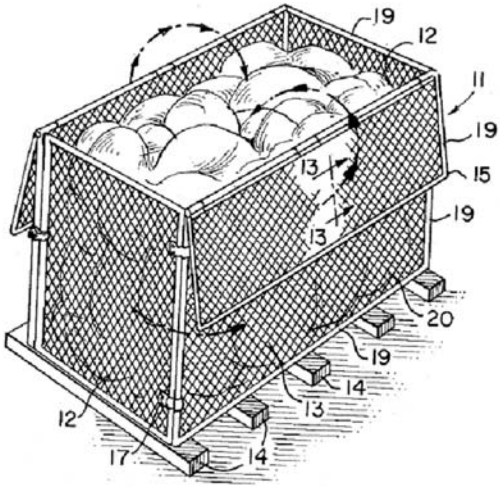

Figure 6.22 Schematic perspective of a rectangular receptacle loaded with waste bags (1993, **US3831340** A, TULKOFF M). 11, Rectangular receptacle; 12, End walls of the receptacle; 13, Side walls of the receptacle; 14, Skids; 15, 16, Top hinged doors; 17, Hinges; 19, Rectangular metal frame; and 20, Grid of wire.

of the receptacle, at least the inside of the receptacle is given a coating treatment with a plastic release material.

WO2008135757 A1 (2008, TAYLOR PRODUCTS LTD) discloses a method and an apparatus for processing heterogeneous waste, such as domestic waste comprising: 1) feeding the heterogeneous waste material into a compaction compartment, wherein the compaction compartment defines a progressively tapering waste processing path that diminishes in diameter as waste proceeds along the processing path; 2) transporting and compacting the waste material through the compaction compartment toward an outlet; 3) heating the compacted waste in a heating zone to a temperature that facilitates melting of low molecular weight polymers located within the waste but which is below the carbonization temperature of either the polymers or the organic matter within the waste; and 4) extruding the compacted and heated waste from the heating zone through an extrusion nozzle to produce compacted and sterilized waste, which is encapsulated within the melted polymers comprised within the waste. Low melting point polymers include, for example, film waste and bottles comprising high-density polyethylene, low-density polyethylene, polypropylene, and PVC. **WO2012035308** A2 (2012, MASSMELT LTD) discloses an alternative method and apparatus comprising further a cooling zone including a cooling arrangement for cooling the waste material received from the heating zone. Although the aforementioned apparatuses are designed to handle a diverse heterogeneous waste stream, it is also possible for homogeneous waste material to be processed and compacted. The type of waste to be compacted will largely depend on the location of the apparatus. For example, a compactor located on a cruise ship may be required to process significant quantities of generally plastic waste, whereas a compactor situated behind a supermarket or shopping mall may be used to process single-use plastic packaging such as carrier bags or shrink wrap film used to wrap pallets of goods.

6.2.3 Bales

Flexible plastic packaging waste that is to be recycled is often pressed into bales for transportation. The baling of plastic film into large, compact bundles is a standard practice for most recycling centers, where films are consolidated and trucked or shipped to processing facilities. By baling the loose films, recycling centers can save on space and lower logistic cost. Plastic film bales vary in size, depending on the type of baling equipment used and the experience of the operator; however, most bales are about 1−1.5 m in length, width, and height with each bale weighting about 200−700 kg [26].

Mixed flexible plastic bales have lower economic value than completely segregated material. This leads to a lower incentive for MRFs and recyclers to focus on multimaterial flexible packaging that is very lightweight and does not take up much volume. Bales of curbside film have about one-sixth of the value of mixed film that comes from retail collection programs, due to contamination of curbside film during collection and processing in MRF [5]. Odors and leakage from residual food packaging is a potential issue when accumulating and storing materials for sale to recyclers. Occasionally, collected mixed flexible film bales are shipped to a PRF where the plastics are sorted by polymer type and formed into bales of higher purity.

Most plastic recyclers are currently experiencing sharp decreases in bale quality and yields. It is very difficult to evaluate the contents of a bale of flexible packaging films simply by looking at it, so creating and implementing bale specifications will improve separation selectivity, which is a prerequisite for obtaining recyclates of high and constant quality. Plastics Recyclers Europe released a set of bale quality guidelines to drive market transformation toward circularity. The guidelines aim at improving the quality of the collected and sorted plastics, and in turn increasing the quality of input that reaches the recycling plants. The guidelines serve as information benchmarks to suppliers of any collected waste. There are bales characterization guidelines for polyethylene [27] and polypropylene films [27].

The Association of Plastic Recyclers (APR), representing over 90% of the postconsumer plastics recycling capacity in North America, has also developed model bale specifications for plastic films. APR's Model Bale Specifications have seven standard components:

- bale content overview;
- acceptable levels of contaminants;
- contaminants not acceptable at any level;
- warnings;
- bale size/minimum shipping weight; and
- bale wire.

There are model bale specifications for specific plastic films[6]:

- MRF curbside film [29];
- polyethylene clear film [30];
- polyethylene retail bags and film [31]; and
- LDPE furniture mix film [32].

The bales are typically tied using strings such as steel wires, tapes, strips, cords of twined or otherwise mutually engaged filaments, and the like. When processing the plastic waste, string material tends to become entangled in machinery, thereby reducing effectivity and/or efficiency of operation and causing damage to the machinery. In particular, in sorting screens, string material tends to be wound-up around shafts and rotor bodies of the sorting screen. Although it has been attempted to reduce the tendency of string material to wind-up in sorting screens by providing special rotor designs, winding of string material still occurs and removal of string material from sorting screens is cumbersome and requires the sorting screen to be stopped, which reduces productivity (2017, **EP3165291** A1, BOLLEGRAAF PATENTS AND BRANDS B V).

Some types of flexible plastic packaging are highly compressible such that when compacted in a baler the volume the waste occupies in the bale can be significantly reduced. For example, used plastic bags and plastic

[6] Model specifications for agricultural films have been omitted as falling outside the scope of this book.

shrink wrap are pliable and also highly compressible. Other types of flexible plastic packaging, however, may be less compressible. However, there is the problem that compressed bales of waste material with polyethylene films include air pockets. These cause after tying special expansion forces in the bale, which can lead to the tearing of the wires. For this reason, these bales are currently not so highly compressed, which has the disadvantage of transporting low-density bales (1994, **DE9407754** U1; 1995, **WO9531374** A1, LINDEMANN MASCHFAB GMBH).

There are two general types of balers: vertical, or downstroke, and horizontal. Some representative commercial balers for flexible packaging waste such as plastic bags and plastic films are:

- Bollegraaf's bales (HBC series) [33].
- Maren's plastic film recycling horizontal automatic tie balers; the plastic film recycling two ram baler; and closed door manual tie balers [34].
- HSM's vertical balers (HSM V series) [34].
- The horizontal balers (both manual tie and automatic tie) and standard mill size balers of Ningbo Sinobaler Machinery Co. Ltd. [36].

US2007020410 A (2007), **CA2593836** A1 (2008), and **US2009148629** of PAPER AND PLASTIC PARTNERSHIP describe various approaches that are used to track the weight of recyclable waste that is pressed into a bale.

One efficient way is to measure the thickness of each layer of a distinct type of recyclable material and multiply that thickness times other known constants such as the dimensions of the bale to determine an approximate volume. This number is particularly helpful for use in determining the value of the recyclable plastic film that has been recovered. For example, it is currently known that every 3 in of compacted plastic film in a bale measuring 60 in × 48 in × 30 in weighs about 50 lb (22.7 kg). A 72 in × 48 in × 30 in bale in turn weighs about 65 lb (29.5 kg). Thus, on the formation of the bale, the thickness of a layer of plastic film can be approximately measured in inches and a weight estimate can be made.

In another way, the thickness of a recyclable waste layer can be estimated as a fraction of the bale thickness. Regardless, the entire bale can also be weighed so that the correct fractional portion of the load is assigned to the recyclable waste.

In yet another alternative, past measurements of the various types of recyclable waste by-products included in the composite bales can be used. For instance, for a particular size of bag, historical averages for the various types of recyclable waste can be calculated and used to estimate the weight of each type of waste material in the bale. Accordingly, on creation of the bale, the retailer can indicate on the bale, or on the shipping documents, the number of bags of each type of recyclable waste by-product that is in the bale. In this manner, when the bale is received by the processing facility, the processing facility can calculate the approximate weight of each recyclable material even without separating the bale. The processing or recycling facility can also separate the bale and count the bags of each type of product to, verify, for example, the retailer's count and/or to update historical average data.

The historical weight averages may also be used even without an indication by the retailer of the number of each type of product in the bale. For instance, the processing facility may merely separate the bale and count each type of bag. To facilitate such counting, each bag may contain only one type of recyclable waste by-product. Further, each type of by-product may be enclosed in a different color bag such that the by-product therein can easily be identified by the processing facility even without opening the bag. Alternatively, indicia may be provided on the container enclosing the by-product (e.g., a description or picture of the by-product) to facilitate identification, or the bags may not include any indicia or other method for distinguishing between types of content.

For a more accurate measurement of the recovered waste products, the whole bale can be weighed at the processing or recycling facility. Thereafter, after the bale is broken open and the various types of recyclable waste are separated, each bag can once more be weighed to get a final accurate measurement of the recovered amount.

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(*Continued*)

(*Continued*)

Patent Number	Publication Date	Family Members	Priority Numbers	Inventors	Applicants	Title
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