8 Post-processing and Reuse

8.1 Cleaning

Plastic packaging film cleaning is an integral part of the plastic film recycling process. Cleaning can run simultaneously with or follow the size reduction and usually involves a succession of cleaning steps to remove solid and liquid waste residues adhering to the film. Cleaning can be carried either in a wet state or in a dry state.

8.1.1 Wet Cleaning

The wet cleaning of scrap films is mainly performed with water, optionally in combination with a surfactant. An alternative type of wet cleaning is using solvent (see Chapter 7, Section 7.2). The cleaning with water (washing) performs several tasks, including [1]:

- removal of food residues;
- removal of dirt, dust, and glass grit the film picks up during processing at a material recovery facility (MRF);
- pulping and removal of paper and stripping of plastic labels adhered by water-soluble adhesives;
- preliminary separation of polymers that have a higher density (e.g., PET, PLA) from those that have a lower density than water (e.g., polyethylene, polypropylene).

Washing plastic film includes size reduction, followed by washing in (heated) water containing detergents and wetting agents, taking place under agitation in a series of containers. Washing is followed by drying of the packaging film.

A typical washing line of a scrap film comprises the following steps and/or equipment [2]:

1) Size reduction of the scrap film carried out by a shredder or wet granulator, which also has the effect of washing away some of the dirt.

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2) Transport the film through a friction washer/dryer; this is similar to a screw conveyor, which transports the material up the screw, while water is introduced at the top and drains from the bottom. The countercurrent flow of the water further cleans the plastic, while the agitation of the screw loosens any adhered items such as labels and also dries the plastic to a moisture level of about 30−40%.
3) Immerse the scrap film into a tank containing either hot water or (rarely) a hot caustic solution and agitate it. The heat and agitation remove labels from the film and dissolve the glue. This can either be done in batches or continuously. Washing can also remove surface-printed inks; washing does not remove inks that are reverse printed on the inside of multilayer bags and pouches [3].
4) Use of a screw press conveyor to mechanically squeeze more water out, leaving 8−15% moisture, before a hot air or friction drying system is used to reduce the moisture content to below 2−3%, so it is suitable for extrusion.
5) Treatment of the generated wastewater [2].

The main disadvantages of scrap film washing can be summarized as follows:

1) The rate at which scrap film can be conveyed throughout the system, the rate at which the extruder can process, and the volume of wastewater that the attached treatment plant can deal with.
2) The large amount of water needed for the cleaning of scrap film. Some plants use dry cleaning equipment ahead of the wet washing process to remove contamination as much as possible before the material enters the water bath. This reduces the load on the wastewater treatment.
3) The large amount of energy required for drying the washed film. The annual cost (capital and O&M[1]) of washing and drying is estimated to about $400/ton [3].
4) Greater capital equipment cost compared with dry cleaning. However, it is estimated that the capital equipment cost and associated labor cost will decrease as film is recycled in larger volume throughput facilities. This means that unlike dry recycling facilities,

[1] Operation and Maintenance.

there are cost advantages to large film washing facilities compared with small ones [3].

Water quality and energy consumption are of paramount importance in plastic film washing. The presence of contaminated or not appropriately filtered and treated water will compromise the quality of the washing process, the floating efficiency, and wear of machine parts. A representative example of wet washing is the Sorema film recycling process, which is considered to be "best practice" for plastic film wet washing [2]. Sorema's washing lines are equipped with specific in-line systems for water recirculation and filtration (see also Section 8.6).

The energy cost required to dry the film on a cost per lb basis is constant, irrespectively of whether larger volumes are processed by bigger facilities. Some film recycling equipment suppliers have designed integrated film recycling lines that do not require separate pieces of equipment for drying, densifying, and extruding film. Such an equipment supplier is Erema that developed an integrated film recycling equipment that can accept film with 12% residual moisture, which the equipment then dries, densifies, and extrudes (energy is still required by this piece of equipment to evaporate the residual moisture) [3].

Flexible multilayer packaging films may either sink or float during washing depending on the relative amounts and densities of the constituting polymers. Washing cannot remove labels that are adhered by water-insoluble adhesives. Certain polyethylene retail sacks imported from Asia contain more than 10% fillers and would rather sink than float, reducing the total amount of polyethylene film that is washed [1] (see also Section 8.4.1).

In the conventional process of washing a discarded flexible plastic packaging composed of wrapping materials covered with organic wastes from food rests, there has been used, for example, an apparatus capable of separating therein the flexible plastic packaging into the wrapping materials and the adherents, washing the wrapping materials, and outputting them in a separate manner. Such an apparatus as disclosed in **JP2003320264** A (2003, KANEMIYA KK) has a feed port through which the flexible plastic packaging is loaded; a cylindrical process tank communicated with the feed port and allowing therein separation of the flexible plastic packaging into the wrapping materials and foods; a discharge port and a discharge path, provided to the process tank, through which the adherent and the wrapping materials, after being separated, are respectively discharged; a drive shaft provided in the process tank and rotated by a motor; and a plurality of rotating blades having the base ends thereof, respectively fixed on the drive shaft, and having the tip ends located so as to be opposed with the inner circumferential surface of the process tank. In the process tank of this apparatus, there are provided jetting nozzles through which a treatment agent (water, oil, or water/oil mixture) is jetted into the process tank. The treatment agent jetted through the jetting nozzles into the process tank prevents the undesirable kneading of the adherent foods, even if the enclosed foods were raw pasta, such as Japanese wheat pasta (udon) or Japanese rice cake (mochi), and facilitates their discharge.

According to **US2012160282** A1 (2012, HASEGAWA TOSHIHIRO), the wrapping materials separated by the apparatus of **JP2003320264** A had residues of foods remained thereon, so that putrefaction of the residues have often resulted in offensive odor.

JP2005058845 A (2005, KANEMIYA KK) discloses an apparatus aiming at solving the aforementioned problems having washing brushes attached to the ends of the rotating blades. The apparatus is configured to fix the washing brushes so that the ends thereof are positioned close to the inner circumferential surface of the process tank and are allowed to be brought into sliding contact with the wrapping materials as the drive shaft rotates. The apparatus is aimed at forcedly separating residues previously adhered on the wrapping materials, making use of washing water jetted through the jetting nozzles and the washing brushes and, thereby, preventing the offensive odor.

The apparatus of **JP2005058845** A has been suffering from a problem that the offensive odor could not completely be removed even after the adherents were separated from the flexible plastic packaging. This is because the treatment agent jetted through the jetting nozzles is water, oil, or water/oil mixture, having no sterilizing activity, so that the wrapping materials, even visually judged as being clean without any recognizable adherent, may still carry destructive fungi contained in the organic wastes. Accordingly, any efforts of recycling the plastic, previously composing the wrapping materials output from the conventional washing apparatus, after being pelletized for the purpose of recycling them as source materials for new products, have been successful only in a limited range of products due to offensive odor possibly emitted from the new products. The efforts have alternatively resulted in large devaluation of the source plastics to be recycled, due to the offensive odor (2012, **US2012160282** A1, HASEGAWA TOSHIHIRO).

US2012160282 A1 (2012, HASEGAWA TOSHIHIRO) discloses a washing apparatus aiming at solving the aforementioned odor problem by effectively cleaning and deodorizing deposits attached to flexible plastic packaging. The flexible plastic packaging is a film-, sheet-, or bag-like product previously used as a wrapping material for foods or as an agricultural material, and it is composed of poly(vinyl chloride) (PVC), PET, or the like. The washing apparatus (1) according to an embodiment shown in Fig. 8.1 includes a feeding port (11) through which the flexible plastic packaging is loaded; a processing tank (31) laid while horizontally aligning the longitudinal axis thereof, having one end thereof communicated with the feeding port (11), having therein a housing space for housing the flexible plastic packaging, and a plurality of openings formed in the bottom surface thereof; a rotating shaft (72) arranged in the processing tank (31) and rotated by a drive motor (21); a plurality of rotating blades (81−84, 86−89) having the base ends thereof respectively fixed on the rotating shaft (72) and the tip ends are positioned inside the processing tank (31); a discharge passage (69) formed at the other end side of the processing tank (31) and through which the washed plastic packaging is discharged; a washing water spraying nozzle (not shown) for spraying washing water to the upstream side in the processing tank (31); and a sterilizing water spraying nozzle (not shown) for spraying sterilizing water to the downstream side in the process tank (31), relative to the position of the washing water jetting nozzle.

The washing apparatus (1) is a constituent of a washing facility (110) shown in Fig. 8.2.

CN103240809 A (2012, NANTONG INT PLASTIC ENG CO LTD) discloses a plastic film recovery and cleaning apparatus, shown in Fig. 8.3, comprising a tank body (1); a feeding port (2) arranged on the upper portion of the tank body; a water inlet (3) arranged on one side of the tank body (1); a discharge port (4) arranged on the other side of the tank body (1); a drain port (water outlet) (5) arranged at the bottom end of the tank body; a rotating drum (6) arranged inside the tank body (1) and connected with an electric motor (8) through a rotating shaft (7). A plurality of tapered tines (9) are disposed outside the rotating drum (6), a plurality of fins (10) are disposed in the discharge port (4), and a filter screen (11) is disposed at the drain port (5). The apparatus is claimed to be effective in cleaning and easy to use.

The apparatus is claimed to have the following disadvantages: (1) because of the limited space inside the tank, the plastic film cannot be completely unfolded, and as the film is light, it will float on the water surface, and a part of the plastic film will be exposed on the water surface, resulting in a smaller contact area between the film and the water; as a result, the plastic film cannot be thoroughly washed; (2) the clean water entering the water inlet and the wastewater generated during the cleaning

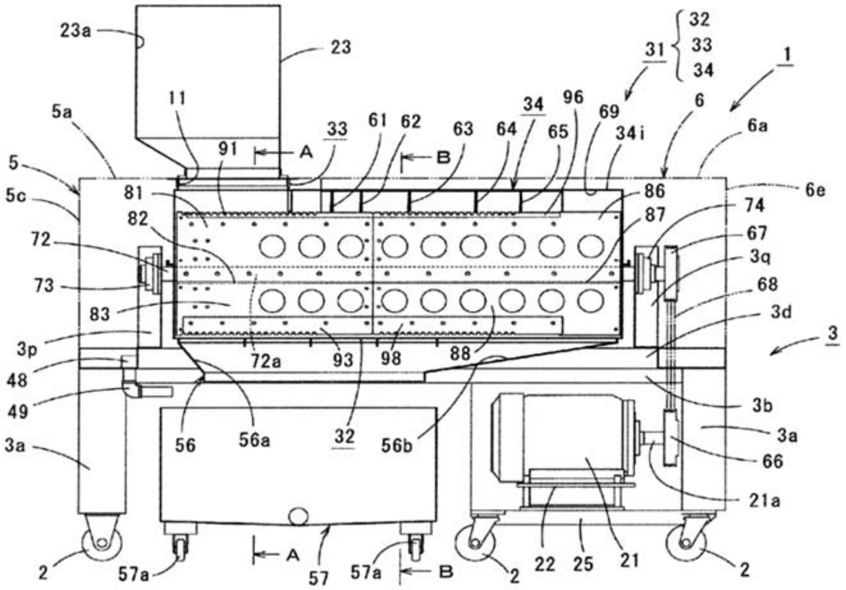

Figure 8.1 Schematic diagram of an apparatus for washing a discarded flexible plastic packaging according to an embodiment of the invention (2012, **US2012160282** A1, HASEGAWA TOSHIHIRO). A, Direction line; B, Direction line; 1, Washing apparatus; 2, Six casters; 3, Frame; 3a, Four support columns; 3b, Cross beams; 3d, Base frame of 3; 3p, Upstream-side bearing frame; 3q, Downstream-side bearing frame; 5, Upstream cover; 5a, Top plate; 5c, Side plate; 6, Downstream-side cove; 6a, Top plate of 6; 6e, Downstream-side plate of 6; 11, Feeding port; 21, Drive motor; 21a, Output shaft; 22, Mounting base; 23, Hopper; 23a, Flow path; 25, Motor frame; 31, Processing tank; 32, Open-top process tank body; 33, Feed frame; 34, Rid; 34i, Discharge frame; 48, Opposing gutter; 49, Drain; 56, Funnel; 56a, Main body; 56b, Inclined portion; 57, Reservoir tank; 57a, Four casters; 61–65, Guide ribs; 66, V-pulley; 67, Driven side; V-pulley; 68, Three V-belts; 69, Discharge path; 72, Rotating shaft; 72a, Square portion; 73, Rolling bearing; 74, Rolling bearing; 81–84, Rotating blades; 86–88, Rotating blades; and 91, 93, 96, and 98, Comb-like elements.

process of the plastic film are mixed in the tank body, wherein the plastic film is cleaned by the mixed water. Because the film is confined in the tank body, more wrinkles are formed, the dirt in the mixed water enters the

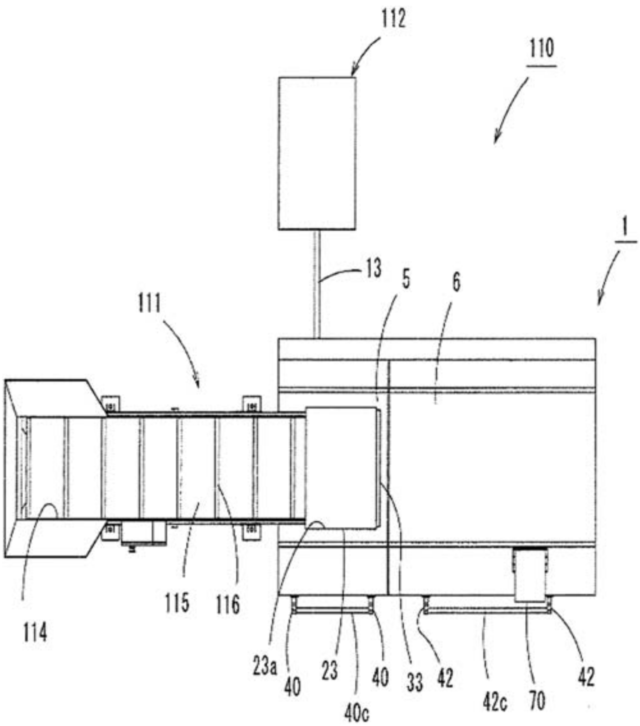

Figure 8.2 Schematic diagram of a washing facility equipped with an apparatus for washing a discarded flexible plastic packaging (2012, **US2012160282** A1, HASEGAWA TOSHIHIRO). 1, Washing apparatus; 5, Upstream-side cover; 6, Downstream-side cover; 13, Aqueous HClO solution feed pipe (tube); 23, Hopper; 23a, Flow path; 33, Feed frame; 40, Two locking components; 42, Locking component; 42c, Handle bar; 70, Discharge duct; 110, Washing facility; 111, Conveyor unit; 112, Weakly acidic aqueous HClO solution production unit; 114, Feed port; 115, Circulating conveyor belt; and 116, Anti-slipping ribs.

wrinkles, and the dirt cannot be completely taken out during draining, so that the plastic film is not adequately cleaned (2017, **CN106738455** A, CHONGQING YAOHONG FOOD CO LTD).

CN106738455 A (2017, CHONGQING YAOHONG FOOD CO LTD) discloses a plastic film cleaning and recycling apparatus claiming to overcome the aforementioned problems (see Fig. 8.4). The apparatus comprises a tank body (1) internally provided with a rotating drum (4). An electric motor (3) is arranged below the tank (1). A feeding port (5) is formed at the top of the rotating drum. A rotating shaft (7) is arranged in

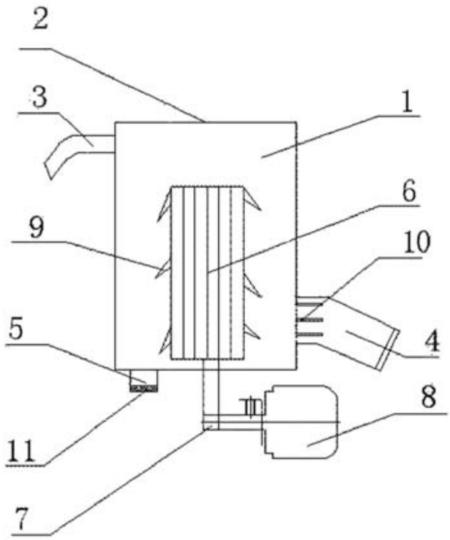

Figure 8.3 Schematic view of a plastic film recycling and cleaning apparatus (2012, **CN103240809** A, NANTONG INT PLASTIC ENG CO LTD). 1, Tank body; 2, Feeding port; 3, Water inlet; 4, Discharge port; 5, Drain port; 6, Rotating drum; 7, Rotating shaft; 8, Electric motor; 9, Tapered tines; 10, Fins; and 11, Filter screen.

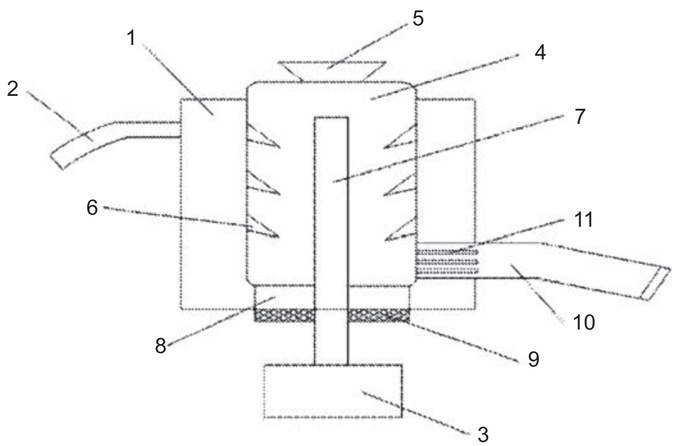

Figure 8.4 Schematic view of a plastic film recycling and cleaning apparatus (2017, **CN106738455** A, CHONGQING YAOHONG FOOD CO LTD). 1, Tank body; 2, Water inlet; 3, Electric motor; 4, Rotating drum; 5, Feeding port; 6, Tapered tines; 7, Rotating shaft; 8, Drain port; 9, Filter screen; 10, Discharge port; and 11, Fins.

the rotating drum. The rotating drum is connected with the motor through the rotating shaft. Water inlet holes (not shown) are formed in the two sides of the wall of the rotating drum. Water outlet holes are formed in the bottom of the rotating drum. A drain port (8) is formed in the lower portion of the rotating drum. Further, a plurality of tapered tines are provided on both sides of the inside of the rotaring drum. Tapered tines can tear the plastic film into small pieces for easy cleaning.

The apparatus is claimed to have the following advantages: 1) the clean water enters into the rotating drum from the inlet holes, and the impact force of the water in the multidirectional direction of the inlet holes immerses completely the plastic film in the water, and the plastic film does not float on the water surface; 2) as the plastic film is cleaned in the rotating drum, the clean water in the tank and the wastewater after cleaning the plastic film in the rotating drum are separated, and the wastewater flows out from the water outlet hole at the bottom of the rotating drum, thereby improving the cleaning quality.

CN106426638 A (2017, SUZHOU DEGRADATION PLASTIC MACHINERY COMPANY) is a modification of the above apparatus; it discloses a waste film cleaning and recycling process comprising the steps of: 1) conveying the waste film into a size reduction device, so that the film is cut to small pieces; 2) conveying the film pieces into a double-screw cleaning machine and cleaning with water at a temperature of 25−35°C for 10−20 min, so that impurities in the film pieces are removed; 3) feeding the cleaned film pieces into a centrifugal dewatering machine, so that moisture is removed from the film pieces; 4) introducing the obtained film pieces into a dryer and discharging the recycled product into a material bin. The disclosed process is claimed to clean the waste film efficiently and rapidly.

8.1.1.1 Friction Washer

A friction washer or friction separator is a water high-speed cleaning machine for mixed plastics. The system cleans materials with a high contamination or persistent dirt, for instance, film flakes. B+B (DE) manufactures friction washers, which are optimum combined with hot washers. The friction washer, equipped with a high-speed revolving rotor, conveys the polluted ground material through the housing. A cleaning solution that is constantly refreshed flows in the opposite direction. The rapid rotations allow the contaminants to rub off and break down into small particles. The inner screen tube functions as dewatering device and filter for contaminants. B + B's friction washer follows the (plastic) hot washer as a rinsing unit in the plastic recycling process [4].

The Neue Herbold (DE) manufactures the friction washers FW Series, shown in Fig. 8.5, which are used to intensively wash plastic materials such as film flakes [5]. The friction washers are mounted on an inclined frame. The material enters at the lower end of the washer with vertical infeed. The special angular flights in conjunction with the high rpm of the shaft transport the material in an inclined direction toward the top of the unit and simultaneously executes the washing phase. Fines, water, and soaked fibrous paper are separated through the perforated screen cage that surrounds the high-speed shaft and allows the separated material to flow down through the friction washer housing to the lower discharge pipe. The device is equipped with water injection nozzles that spray the fresh water

Figure 8.5 The Neue Herbold friction washers FW Series [5]. *Courtesy of Neue Herbold.*

or recycled water directly at the screen cage to assist in screen cage cleaning and prevent clogging. In conjunction with the water spray, the friction washer is manufactured with a pneumatically operated mechanical screen cleaner.

A high-speed friction washer manufactured by ASG Environmental Science Research and Development Institute (CN) comprises a long, fast-rotating shaft (1000 rpm) mounted with many tilted panels or paddles. Surrounding this rotating shaft is a mesh screen tunnel used for dewatering. These are then encased within a rectangular box where water jets and nozzles are mounted and directed at the mesh screen. The entire machine is set at an incline with plastic films being fed into a vertical feeder located on the lower end and cleaned plastic films exiting at the top. The spinning panels constantly hit the film pieces at high speeds causing friction to occur. As the film pieces are rubbing against each other, debris is scrubbed off and thrown at the mesh screen via centrifugal force. Finer particles of dust, dirt, and water exit the chamber at this time. The water jets continuously spray water at the mesh screen reducing clogging and adding water into the friction chamber [6].

8.1.1.2 Drying

Drying of the wet film is usually accomplished by first squeezing the water out and, then, evaporating it through direct application of heat, heating through friction, or application of vacuum [1]. Shreds of film tend to trap and sandwich water between the sheets, unlike bottle flakes that are rigid and more easily shed water droplets. This makes drying film harder and more costly than drying rigid plastics [3]. In general, washing and drying, especially of postconsumer flexible plastic packaging, have high-energy demands.

There are two generally accepted methods of drying plastic films in a washing line. The first and more common method is via a dewatering machine or horizontal centrifuge accompanied with thermal heaters. The dewatering machine removes excess water via centrifugal force. Dewatering can bring the water content of wet plastic films down to about 20−30%. The rest of the water is removed via a thermal dryer, much like a hair dryer.

The second, more economical method, uses a screw press to mechanically squeeze and twist the plastic film. A dewatering screw press has a screw shaft of increasing diameter. The screw shaft is most narrow at the opening where the plastic film first enters via a vertical feeder. Surrounding the screw shaft is a thick-walled, constant diameter outer tube lined with tiny holes for water outlet. The common dewatering screw press for plastic film washing lines is 4–6 m long, but can be increased or decreased based on application. As the wet plastic film enters the screw press, the screw shaft slowly rotates moving the plastic film forward. As the screw shaft becomes thicker in diameter, the plastic film becomes more and more compacted against the outer casing wall. The water from the plastic film is squeezed out and discharged via the tiny holes [6].

At the end of the horizontal screw press, the diameter of the screw shaft is only slightly smaller than the inside diameter of the outer casing. It is through this narrow gap that the dried plastic film exits the screw press. A screw press can bring moisture content down to or below 15% [6].

8.1.2 Dry Cleaning

In dry cleaning, the scrap film is subject to shearing from high-speed rotating blades within a confined space in the absence of water. Dry cleaning is used for relatively clean monomaterial films. Where levels of contamination are relatively low, dry cleaning can be used as a stand-alone process. Dry cleaning can also be used either upstream or downstream of washing [2]. Dry cleaning can remove 80–90% of contamination [7]. The annual cost (capital and O&M) of dry cleaning is estimated to about $200/ton.

The main advantage of dry cleaning is that it eliminates the use of water or chemical agents, and as a result, it does not have the problems associated with drying and wastewater treatment. In addition, there is not a lot of capital equipment required by film recyclers for the dry approach, especially for very clean film, so small-scale facilities can enter the business and be competitive with large-scale facilities. There is not a large economy-of-scale advantage for larger dry film recyclers compared with smaller dry film recyclers [3].

CN201776854 U (2010) and **CN101954677** A (2011) of ZHANGJIAGANG LIANGUAN ENVIRONMENTAL PROT TECHNOLOGY CO LTD disclose a cleaning apparatus, which can remove impurities and dust from waste plastic films in a water-free manner (see Fig. 8.6). The water-free cleaning apparatus comprises: a rotary drum (2) and a housing (3), wherein the rotating drum (2) is arranged on a centrifugal separator (1), and the housing (3) is disposed above the rotating drum (2); a feed inlet (4) is arranged at the bottom of the rotating drum (2), the

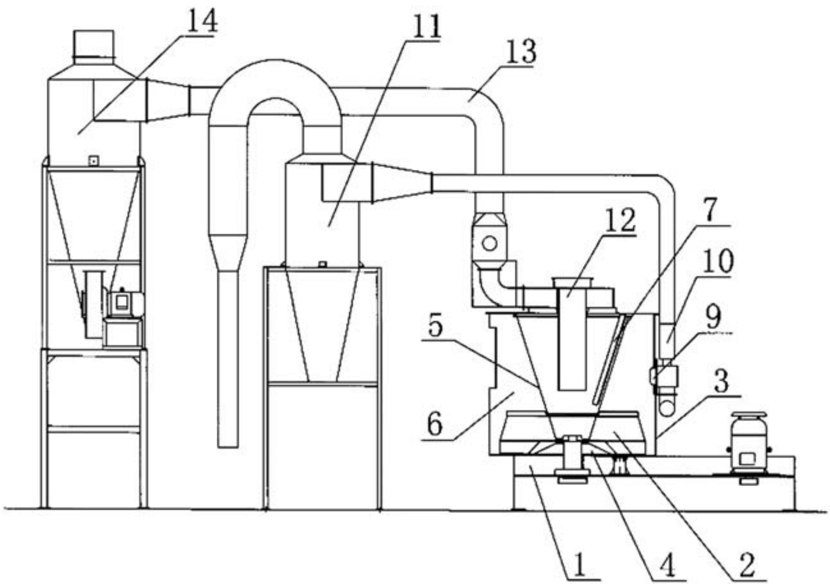

Figure 8.6 Schematic diagram of a waste plastic film, water-free cleaning apparatus (2010, **CN201776854** U, ZHANGJIAGANG LIANGUAN ENVIRONMENTAL PROT TECHNOLOGY CO LTD). 1, Centrifugal separator; 2, Rotating drum; 3, Housing; 4, Feed inlet; 5, Conical screen; 6, Screen; 7, Vent pipelines; 9, Material outlet hole; 10, Pipeline; 11, Storage bin; 12, Dust suction opening; 13, Waste discharge pipeline; and 14, Waste discharge bin.

rotating drum is provided with a conical screen (5) with a frequently enlarged aperture from bottom to top, a separating space is formed among the screen (5), the housing (3), and the rotating drum (2); a plurality of vent pipelines (7) are disposed on the inner wall of the screen (5) and respectively provided with a plurality of air outlet holes (not shown); a discharge hole arranged on the side wall of the housing (3) is communicated with a storage bin (11) through a pipe; and a dust suction opening (12) is disposed at the top of the housing (3) and communicated with a waste discharge bin (14) through a waste discharge pipeline (13). The water-free cleaning apparatus is claimed to be simple and functional, saving a great amount of water resources, and avoiding secondary pollution after cleaning the waste plastic films.

The main disadvantages of dry cleaning are [3]:

1) Film subject to dry cleaning needs to be clean. Polyethylene film requires careful manual quality control on the front end to remove other polymer films and in some cases perform color sorts.
2) Inks are not removed, so any printing on film results in impurities in and discoloration of the recycled polymer produced from the film.
3) Contaminants, including dirt and tapes, if not removed manually, magnetically, or by air classification, they should be removed, e.g. by screening at the end of the process.

Dry cleaning is also used for the removal of shrink full wrap shrink sleeves from PET bottles [8].

8.2 Size Reduction

Size reduction is the primary step in the flexible plastic packaging's recycling process. Shredders and/or wet granulators are the main equipment of choice for reducing the plastic film into small free-flowing pieces.

Size reduction performs a number of tasks that facilitate the recycling of plastic films:

1) Breaks up large bales of plastic film. Spinning blades mechanically break the compacted bundles of film apart and unwrap stuck together films.
2) Reduces the danger posed by large strips of plastic film and plastic bags of tangling angle conveyors and rotary-based washing equipment, slowing production and damaging the equipment.
3) Improves the free flow of the film from one recycling process equipment to another [6].

8.2.1 Shredders

A shredder is a single-stage, low-speed (3.6−83 rpm), high-torque size reduction machine, which cuts films and high volumes of film feedstock into smaller pieces of about 1- 5 in. A shredder is initially used to cut through entire bales of plastic film into hand-sized pieces. The shredder reduces the volume needed for storage, drops the cost of transportation, and facilitates further processing of the flexible plastic packaging waste by generating a stable flow of the incoming waste. Especially for dual-shaft shredder, which has no screen at the outlet, there could be a wide variation in particle size and shape [6].

Flexible plastic film is difficult to tear. The film has the tendency to wrap around the rotor shafts or rotating blades in string fashion and jam the throughput of the shredder causing poor performance or blockage. The tearing, stretching, and jamming also wears and dulls the blades and further reduces cutting or shredding efficiency. In the case of rotating parallel shafts having blades on them, the plastic material drawn between the shafts results in a high-pressure wedging there between, which tends to cause the shafts to spread. The plastic, thus, passes through the machine without cutting. A sufficient build-up of wound up plastic film can cause friction within the machine, excessive heat buildup, and subsequent meltdown of the plastic material. Removal of the melted plastic requires complete shutdown and disassembly of the apparatus (1994, **US5285973**, ADVANCED ENVIRONMENTAL RECYCLING TECHNOLOGIES).

Special shredding machines have been developed to handle plastic film streams. Such machines are equipped with a water-cooled rotor, which keeps frictional heat to a minimum and prevents meltdown. A typical film shredder will reduce the size of the film down to about 40 mm with a feed rate of about 2.5 ton/h [7].

Individual requirements vary greatly according to the type of film to be shredded. Stretch wrap film is easy to process as it tends to ball up and react more like a rigid plastic purging than a film. Because the material sticks to itself so tightly, it does not unravel in the shredder to pose a wrapping risk but simply shreds into chunks. In this case, a standard rotor is all that is required. On the other hand, in cases of self-feeding films, a specially designed film rotor is required. These rotors ensure that every strand or tail is cut before fully wrapping 360 degrees around the rotor. One such rotor forces each strand or film tail into the valley of its corrugated rotor, where a nip cutter ensures it does not wrap more than 180 degrees. By cutting each tail that attempts to wrap the rotor, the self-feeding of the film is minimized, so it will run efficiently and without issue [9].

The primary criterion for the selection of the proper type of rotor for film shredding is the extent to which the film will stretch, rather than break, during the shredding process. If the film does not stretch much before breaking, it should shred without problem. On the other hand, if the film is very difficult to break because it tends to stretch, a specialized rotor designed for this purpose will be required [9].

The pros and cons of using a shredder for reducing the size of a plastic film can be summarized as follows [6]:

Pro 1: Shredders can cut though entire bales of plastic film reducing the amount of manual labor required.

Pro 2: Shredders operate at low speeds and are much quieter, produce less dust and fines and have low rate of wear and tear (applies to dual-shaft and quad-shaft shredders).

Con 1: Shredders are more difficult to maintain; sharpening and replacing blades can be difficult and time consuming.

Con 2: The size and shape of film shreds are not optimal; the shreds are not uniform and relatively large.

Several apparatuses for and methods of shredding plastic films have been disclosed in the patent literature.

US3545686 A (1970, DUPONT) discloses an apparatus, shown in Fig. 8.7, for shredding plastic films (24) comprising a support frame (11), a movable cutting blade (14) having a sawtooth cutting edge rotatably mounted on the frame, a stationary cutting blade (18) having a sawtooth cutting edge (19), wherein the movable cutting blade, and the cutting edge of the stationary cutting blade are separated from each other by a gap of about 1/16 and 1/4 in and interdigitated on rotation of the movable cutting blade (18) to pierce and tear a plastic film (24) advanced across the stationary cutting blade (18). Plastic film (24) fed into the slot is shredded by the interacting blades and carried away by a suction fan connected to an outlet duct (23) in the lower part of the cutting cylinder housing (22).

US5257740 A (1993) and **WO9407671** A1 (1994) of SPROUT BAUER INC ANDRITZ disclose a method and an apparatus for recycling scrap film, comprising the steps of: 1) wetting the scrap film with a liquid, such as water; 2) removing particulate impurities from the wet scrap film by gravity; 3) washing and shredding the wet scrap film with a washer shredder having a pair of counterrotating, intermeshed rotors; 4) removing particulate impurities including at least one of dirt, metal, wood, glass, heavy plastic, and heavy paper from the washed and shredded scrap film; 5) cutting the scrap film with a rotary knife cutter described in **US4738404** A (1988, SPROUT-BAUER, INC); and 6) rinsing the cut scrap film in multistage gravity fed screen sieves using a rinse liquid to remove additional impurities and form a scrap film product stream and a plurality of rinse liquid streams. The apparatus of **WO9407671** shown in Fig. 8.8 includes a washer-shredder unit (10) upstream from a film cutter (14) to

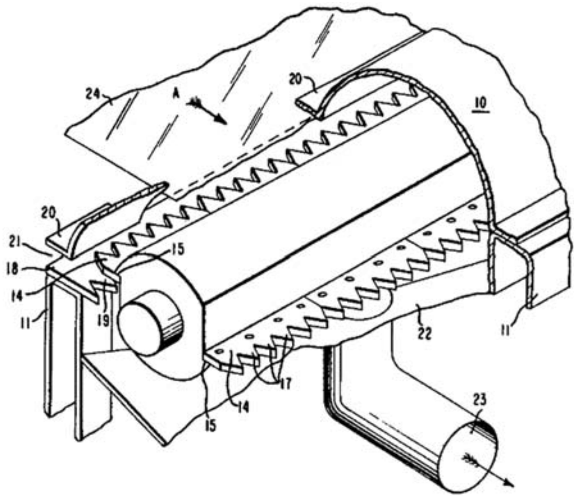

Figure 8.7 Schematic overview of the shredding apparatus (1970, **US3545686** A, DU PONT). A, Direction arrow; 10, Upper housing assembly; 11, Frame assembly; 14, Cutting blades; 15, Recessed shoulders of cylinder; 14, Rotating cutting blades; 17, V-shaped teeth; 18, Stationary cutting blade; 19, V-shaped teeth; 20, Laterally extending flange; 21, Entrance slot; 22, Lower housing assembly; 23, Outlet duct; and 24, Film material.

remove impurities from the film before cutting. Before the scrap film enters the washer-shredder unit (10), it is pre-shredded into strips that are about 1-2 in wide by about 6—12 in long. The pre-shredded scrap film is delivered to the washer-shredder unit (10) by a belt conveyor (20). The apparatus includes wetting means for wetting the film with a liquid. The wetting means includes a wetting tank and means for supplying a washing liquid and a surfactant to the wetting tank. The cutter (14) cuts the washed film into 1/8 to 3/8 in pieces to allow further separation of the dirt from the film. Furthermore, violent agitation is provided during the cutting action to loosen fine dirt particles from the film. The cut film is removed from the cutter (14) through line (40) and is conveyed to further film processing units for rinsing. The method and the apparatus substantially reduce conventional problems with the film cutter (14) caused by impurities that customarily are present in unwashed film. The apparatus is claimed to be particularly useful for recycling very thin scrap film.

US5285973 A (1994, ADVANCED ENVIRONMENTAL RECYCLING TECHNOLOGIES, INC) discloses a shredder including a shredder housing (12) having an inside, an outside, opposed side walls,

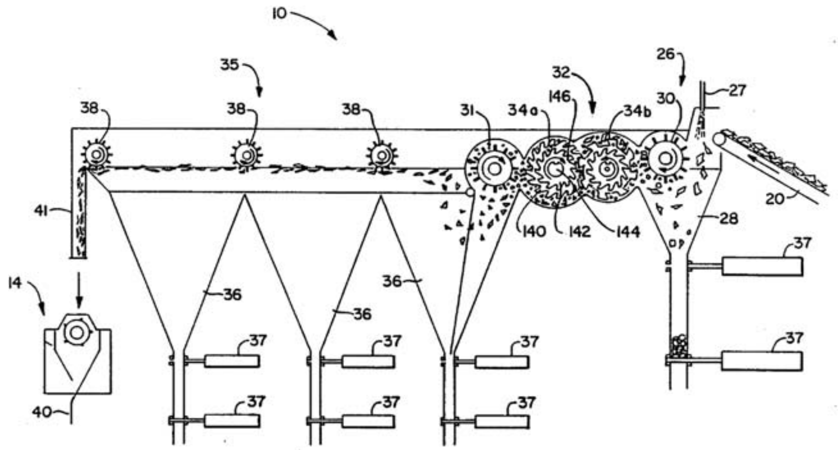

Figure 8.8 Side view of an apparatus for washing and shredding contaminated scrap film (1994, **WO9407671** A1, SPROUT BAUER INC ANDRITZ). 10, Washer-shredder unit; 14, Cutter; 20, Belt conveyor; 26, Wetting-settling zone, 27; Wash water-surfactant inlet line; 28, Wetting-settling tank; 30, 31, Paddle wheel agitators; 32, Washing-shredding zone; 34a, 34b, Pair of interlocking, counterrotating high-speed toothed shredder rotors; 35, Settling zone; 36, Settling tanks; 37, Double dump valves; 38, Down-stream paddle; 40, Remove line; 41, Discharge line; 140, Large blades; 142, Small blades; and 144, Central shaft mounting blades 140 and 142.

and opposed end walls, such that the end walls and side walls are engineered and joined together to maintain tight tolerance within the shredder (see Fig. 8.9). The end walls and side walls define a top inlet opening and a bottom outlet opening. Two parallel, spaced-apart shafts (24, 28) are horizontally aligned with each other and rotationally mounted through the end walls for receiving rotational power. Adjustable speed rotational motors (22, 26) engage each of the shafts for rotating them in counter-rotational directions. A plurality of uniform thickness disk-shaped blades is alternatingly positioned with interposed disk-shaped spacers placed there between. The spacers have a thickness slightly thicker than the blades. The blades and spacers are arranged on the shafts and mounted for counterrotation with the shafts in an interdigitated fashion so that the blades on one of the shafts are aligned with the spacers on the other shaft such that the blades pass side-by-side closely spaced with the blades on the counterrotating shafts in a way that close tolerance cutting occurs

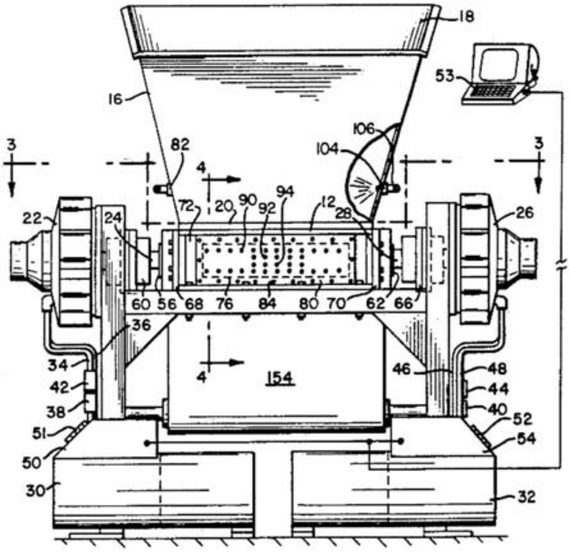

Figure 8.9 Side plan view of a shredder and a hopper (1994, **US5285973** A, ADVANCED ENVIRONMENTAL RECYCLING TECHNOLOGIES). 3–3, Section line; 4–4, Section line; 12, Shredder housing; 16, Feed hopper; 18, Hopper mouth; 20, Housing opening; 22, First hydraulic motor; 24, First shaft; 26, Second hydraulic motor; 28, Second shaft; 30, 32, Pump assemblies; 34, First hydraulic input tubing; 36, First outlet tubing; 38, First input flow and pressure sensor; 40, Second input flow and pressure sensor; 42, First outlet sensor; 44, Second outlet sensor; 46, Second hydraulic input tubing; 48, Second outlet tubing; 50, First control system; 51, 52, Control panels; 53, Computer control panel; 54, Second control system; 56, Bearings; 60, First coupler; 68, First parallel end plate; 72, First side of housing 12; 76, Side opening; 82, Removable side plate; 84, 90, Standard threaded fasteners; 92, First top adjuster; 94, Second bottom adjuster; 104, Second spray nozzle; 106, Coolant supply line; and 154, Conveyor.

between the blades. Close spacing between blade teeth edges and the interior sides of casing further facilitates cutting of thin gauge plastic, including plastic film, such as grocery bags, shrink wrap film, and the like. A conveyor (154) or other means for carrying the shredded plastic for further processing may be positioned below the shredder. To maintain the temperature of the blades and the shearing process below the melting temperature of the plastic material, spray nozzles are provided attached ahead of the input opening as, for example, a spray nozzle (104) at one end of hopper (16) and are supplied with a coolant supply line (106). Keeping the shredder cool facilitates shredding without melting the shredded pieces along the sheared edges. Also, the coolant mist is preferably water that is adjusted to evaporate completely so that dirt particles may be shaken off of the shredded plastic to facilitate recycling processes. Further, melting that might entrap dirt particles at the shear edges is reduced and avoided.

DE29803922 U1 (1998, HOSOKAWA ALPINE AG) discloses an apparatus, shown in Fig. 8.10, for drawing in and feeding strips, films, and plastic bands of different materials into a film shredder comprising a pair of equal diameter, parallel rolls (1, 2) rotating in opposite directions and forming a gap between them (12). Stripper plates (3, 4) located below the rolls on both sides of the gap have internal air channels (5) through which a pressurized gas flows to nozzle openings (6) feeding the gas directly onto the rolls. The pressurized gas prevents film from adhering to the roll surfaces, and efficient use of pressurized gas reduces costs.

DE20308945 U1 (2003, PAVEL WILFRIED) discloses a plastic film and scrap film shredder, shown in Fig. 8.11, having upper and lower converging faces with retractable rows of pins for forward movement and light compression of film. A frame forms a conveying channel (30) for films and has on its base (34) a row of pins (36) that move backward and forward along the length of the channel and can be raised above or lowered below the base surface. A second row of pins (52) above the first row

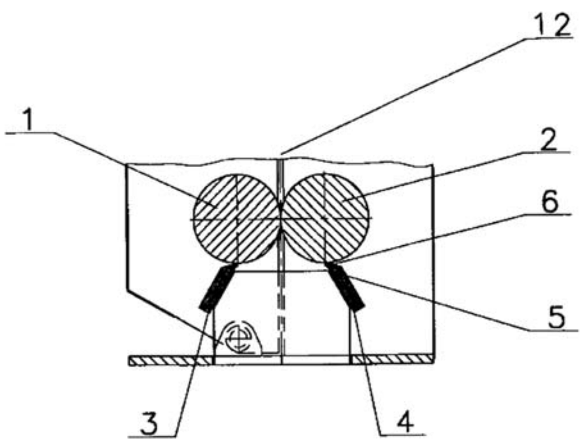

Figure 8.10 Side view of a film shredder (1998, **DE29803922** U1, HOSOKAWA ALPINE AG). 1, 2, Pair of equal diameter, parallel rolls; 3, 4, Stripper plates; 5, Internal air channels; 6, Nozzle opening; and 12, Feed gap.

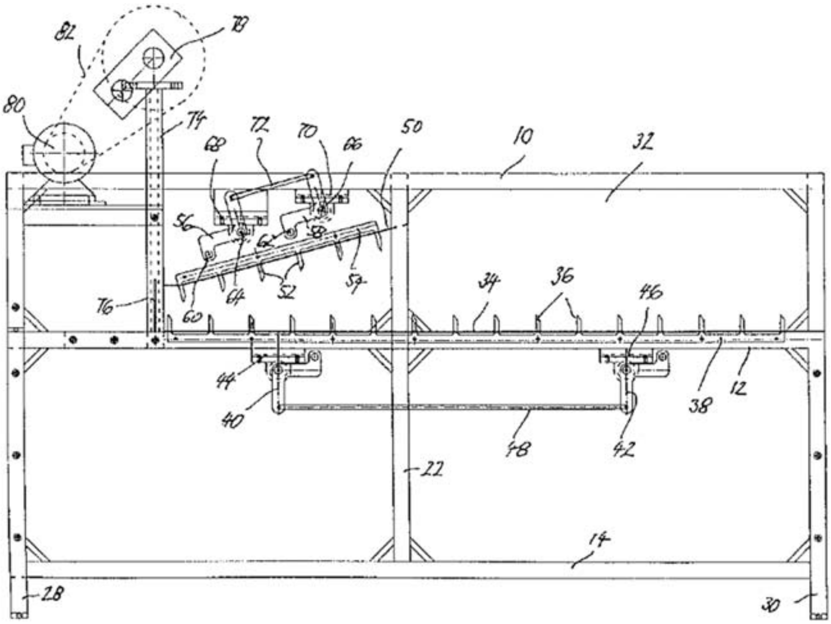

Figure 8.11 Side view of the shredding apparatus (2003, **DE20308945** U1, PAVEL WILFRIED). 10, 12, 14, Longitudinal struts; 18, 22, Vertical connectors; 30, Conveying channel; 32, Collecting groove/channel; 34, Base; 36, Pin row; 38, Supporting bar; 40, 42, Swiveling levers; 44, 46, Slides; 50, Guiding wall; 52, Pin row; 54, Supporting bar; 56, 58, Swiveling levers; 60, 62, Axes; 64, 66, Axes; 68, 70, Slides; 72, Connecting bar; 74, Frame; 76, Knife; 78, Crank mechanism; 80, Motor; and 82, Belt.

and toward the downstream end is raised and lowered by a guiding wall (50) and can also move backward and forward along the channel length. A cutting blade moving across the conveying direction is located at the downstream end. The rows of pins (36, 52) are mounted on common bars (38, 54) each of which is supported on two parallel swiveling levers (40, 42, 56, 58) that raise and lower the bars relative to the base (34). The parallel levers are mounted on two parallel slides (44, 46, 68, 70) that move backward and forward on the frame. Downward inclination of the upper guiding wall (50) in the film conveying direction may be varied by a swiveling action. The shredder is used, in particular, for shredding and recycling of plastic films or scrap film, in particular protective film covers for clothing or packaging films. A compacted block of film is created quickly using low energy levels, and the resulting small cut pieces are less prone to holding air pockets.

CN103240811 A (2013, NANTONG INT PLASTIC ENG CO LTD) discloses an apparatus for cleaning and recovering scrap film shown in Fig. 8.12 comprising a recycling tank (1) with a feeding port (2) that is equipped with cutting blades (3), a first cyclone separator (4), and a discharge pipe (5). A side wall of the recycling tank (1) is connected with a suction pipe (6) that is provided with a suction blower fan (7). The suction pipe (6) is connected with a shredding chamber (8). The upper part of the shredding chamber is provided with a shredder (9); the lower part of the shredding chamber (8) is provided with a second cyclone separator (10); and the bottom part of the shredding chamber (8) is connected with the discharging pipe (11). The apparatus is claimed to have the following advantages: 1) better film recovery; 2) high degree of automation and high efficiency; 3) reduced labor intensity; 4) low manufacturing cost; and

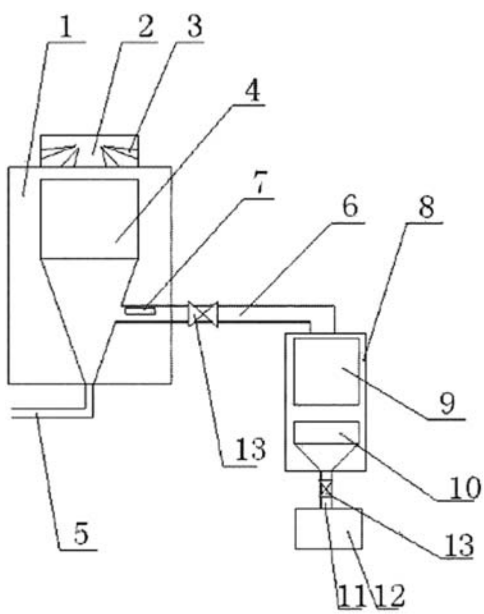

Figure 8.12 Apparatus for cleaning and recovering scrap film (2013, **CN103240811** A, NANTONG INT PLASTIC ENG CO LTD). 1, Recycling tank; 2, Feeding port; 3, Cutting blades; 4, First cyclone separator; 5, Discharge pipe; 6, Suction pipe; 7, Suction blower fan; 8, Shredding chamber; 9, Shredder; 10, Second cyclone separator; 11, Discharge pipe; 12, Collecting bin; and 13, Valve.

5) small floor area. Further, the apparatus can work continuously, is stable and reliable, simple in operation, and convenient to use.

PL406201 A1 (2015, KUTA PAWEŁ; KUTA LESZEK; ŻMIJEWSKI TOMASZ; MAJCHER MONIKA) discloses a method and an apparatus for washing and shredding plastic packaging films. The apparatus has a shredder and a flotation bath that are fixed with a dynamic pressure washer, i.e., a washer tandem. The film is shredded to a size of 100 mm and then is washed in the floatation bath for the removal of impurities. After washing, the film is shredded again to a size of 40 mm.

EP3059061 A1 (2016, MONDI CONSUMER PACKAGING TECHNOLOGIES GMBH) discloses a method for recycling a flexible pouch, comprising the steps of: providing a pouch, as shown in Fig. 8.13A, with a pouch body (1) formed by a pouch wall, wherein the first surface of the pouch wall is formed of a transparent outer film (2) made of PET and the second surface of the pouch wall is formed of a nonperforated inner film (not shown) made of polyethylene or polypropylene, and a visible pressure layer (4) is arranged between the outer film (2) and the inner film through the transparent outer film (2), wherein the inner film and the outer film (2) are connected to each other only at the side edges of the pouch body (5); shredding the pouch, as shown in Fig. 8.13B, wherein at the noninterconnected first pouch wall sections of the outer film and the inner film separated particles (Pi, Pa) are formed; and forming at least a first sorted fraction of particles (Pi, Pa), which are recycled. The recycled particles are used to make new pouches (see Section 8.7).

Representative commercial shredders for flexible plastic packaging waste are:

- Bollegraaf's shredders [10].
- Vecoplan's plastic film and fiber shredders, e.g., RG42K-XL F based on patented SureCut shredding system that delivers built-in two-stage auxiliary size reduction in a single pass [11] (2012, **US2012325950** A1, VECOPLAN LLC); and
- Prosino plastic film shredders [12].

8.2.2 Granulators

Hand-sized pieces of plastic film obtained by a shredder are fed into a granulator, where they are further reduced in size. A plastic granulator (also known as crusher or grinder), unlike a shredder, operates at much higher speeds, around 200–800 rpm, at relatively low torque. A typical

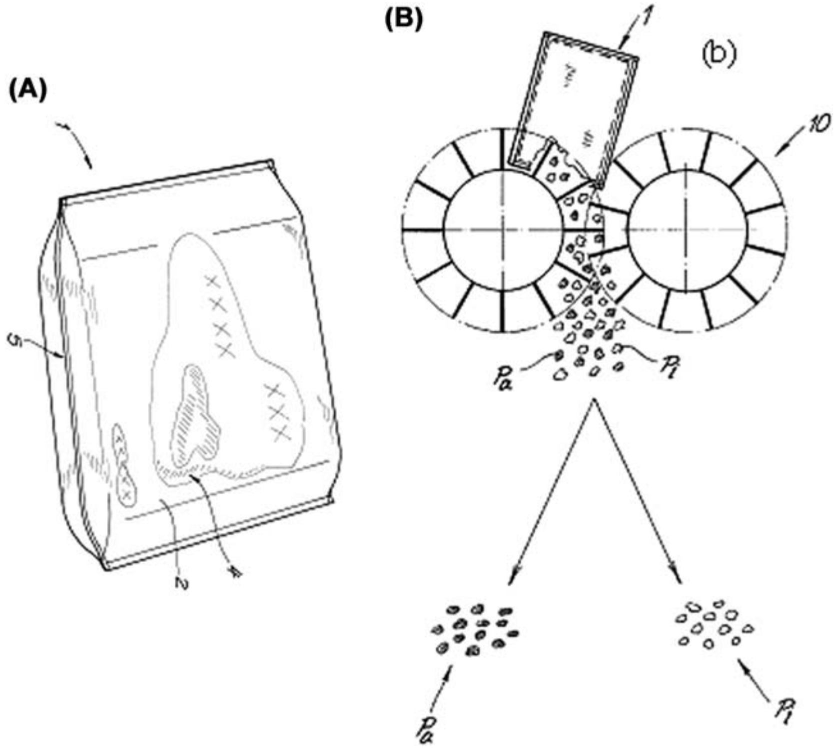

Figure 8.13 Schematic diagram of the method (B) for recycling plastic from a film packaging pouch (A) with a shredder (2016, **EP3059061** A1, MONDI CONSUMER PACKAGING TECHNOLOGIES GMBH). 1, Bag body; 2, Transparent outer film; 4, Visible pressure layer; 5, Side edges; 10, Shredder; and Pa, Pi, Separated particles.

plastic granulator is exemplified by rotating cutting blades housed in a chamber enclosure. Heavy duty knives are mounted at an adjustable angle on an open, hollow rotor in various arrays. When the blades on the fast spinning rotor contact the stationary blades on the granulator housing, the feed stock is cut into relatively fine flakes or regrinds. At the bottom or surrounding the spinning rotor is a sizing screen, a metal screen with holes of about 6−12 mm. A granulator can repeatedly reduce the size of the scrap film until it passes through the holes of the sizing screen, and it is considered the most suitable equipment to produce uniform granules consistently. Although plastic granulators are able to produce smaller sized outputs, the fast rotating parts are noisy and produce high amounts of dust or fines.

For the purpose of washing plastic films, wet granulators are used. In wet granulators, a constant stream of water is sprayed into the cutting chamber. This setup accomplishes size reduction, and at the same time, it cleans dirty films before they reach another set of washing equipment. The added water also acts as a lubricant for the rotating blades to reduce generated heat and friction. A high-speed friction washer is usually placed after a wet granulator [6] (see Section 8.1.1.1).

A wet granulator chamber includes a water spray composed of a plurality of nozzles mounted in the chamber and oriented to direct the spray onto the cutting blades during comminution. However, oftentimes, significant amounts of solid and liquid contaminants are not removed by the clean water spray, and, thus, the flakes that are produced by the granulator are not clean enough for use in an extruder. To remove a sufficient amount of the solid and liquid contaminants from the plastic flakes for such usage, the prior art processes typically employ several repetitive steps of washing and rinsing the flakes with clean water following granulation. If the number of times the flakes are required to be washed and rinsed during the recycling process could be reduced while nonetheless yielding a sufficiently clean flake for end-use requirements, the recycling process would require less clean water and otherwise be more resource-conserving and efficient.

RU2116196 C1 (1998, PANOV ALEKSANDR KONSTANTINOVIC; BIKTIMIROV FARIT VAGIZOVICH; PETROV PAVEL IVANOVICH; IBRAKOV MINNULA SHAJAKHMETOVIC; SHULAEV NIKOLAJ SERGEEVICH; BELOBORODOVA TAT JANA GENNAD E) discloses a grinder for the disintegration of films, sacs, plastic bands, cords, and plastic bundles. The grinding apparatus, shown in Fig. 8.14, comprises a housing (1), a rotor with a set of large (2), with a diameter of 300 mm, and small diameter (3) disc cutters, with a diameter of 285 mm (with teeth similar to a circular saw), mounted on a shaft (4) and fixed with a key (5). A stationary cutter (blade) (6) with a total length of 400 mm is fixed to the housing with a screw (7). The grinding apparatus operates as follows: The plastic waste is fed to the receiving hopper (15). Foreign metallic debris are removed by magnetic traps (16), and the plastic waste is captured by the protrusions of the rollers (10). The protrusions and recesses of the rollers have a special profile (13) to compact the plastic waste and form a web (rather than cut) convenient for grinding with disc cutters. The formed web is then sent to a connecting tube (14) and into the rotor rotation zone, where it is cut to pieces, which then fall through a grid (8), and sucked off by a blower. Pieces of a film with a size of 6.5×7.5 mm

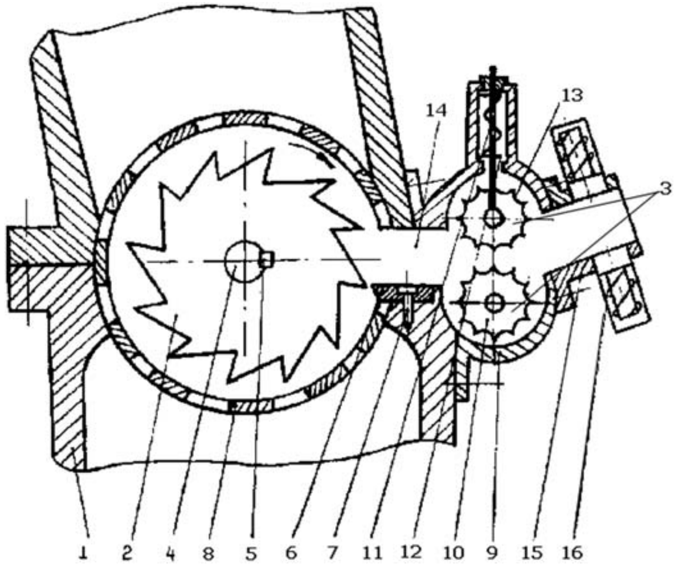

Figure 8.14 Side view of a grinding apparatus (1998, **RU2116196** C1, PANOV ALEKSANDR KONSTANTINOVIC; BIKTIMIROV FARIT VAGIZOVICH; PETROV PAVEL IVANOVICH; IBRAKOV MINNULA SHAJAKHMETOVIC; SHULAEV NIKOLAJ SERGEEVICH; BELOBORODOVA TAT JANA GENNAD E). 1, Housing; 2, Large diameter disc cutter; 3, Small diameter disc cutters; 4, Shaft; 5, Key; 6, Stationary cutter (blade); 7, Screw; 8, Grid; 9, Housing; 10, Rollers; 11, Rods; 12, Springs; 13, Roller's special profile of protrusions and recesses; 14, Connecting tube; 15, Hopper; and 16, Magnetic trap.

were obtained, which were then passed through an extruder to be converted into pellets.

PL414258 A1 (2017, POLIMER COMPOMAX PRZEDSIĘBIORSTWO PRODUKCJI PREFABRYKATÓW KOMPOZYTOWYCH SPÓŁKA Z OGRANIC) discloses a method for the recycling of polyolefins, in particular, LDPE packaging films, from municipal waste. The packaging films are separated from municipal waste on the basis of thickness and color and cut into pieces whose longest side is less than 5 mm, preferably 2 mm, more preferably 1 mm; further, the film pieces, depending on their purpose, are washed with water by adding 1-4 wt% detergent and dried in the open air or at 40−70°C, preferably at 50°C. The cleaned film pieces are subject to granulation to obtain granules with a size 0.5−2 mm.

The pros and cons of using a granulator in plastic film size reduction can be summarized as follows [6]:

Pro 1: Plastic film cut using a granulator is optimum; the cut pieces are relatively uniform and small.

Pro 2: Granulators are easy to maintain; blades can be easily mounted and taken out for sharpening.

Con 1: Granulators cannot take whole film bales; instead, baled films must first be manually loosened and feed into the machine piece by piece. A "bale opener" or "debaler" machine can be added to washing lines to automate this process.

Con 2: Granulators have much higher wear and tear because they operate in high speeds. Operators must be careful about accidently putting hard objects such as metals (nuts and bolts) into the cutting chamber as this will easily damage the blades. The fast-spinning blades may also propel these hard objects causing potential hazards in the working environment.

Con 3: Wet granulator partially cleans and "pretreats" the plastic film.

8.2.2.1 Cryogenic Systems

Cryogenic recycling can be used to separate an embrittled polymer from a more ductile polymer. Cooling can also embrittle the adhesive used in a multilayer plastic packaging. Separation of foils from polymer coatings is especially aided by cryogenics [13].

Many conventional cryogenic recycling processes and apparatuses require the use of liquid nitrogen or solid carbon dioxide to lower the temperature of the material to be recycled to a point where a subsequent impact or cutting produces a powder or granular material. These cryogenic processes are expensive to implement and operate due to the need for a large plant to produce the liquid nitrogen or solid carbon dioxide and the cost of energy required to operate the system.

8.3 Agglomeration

Scrap films cannot be ground up at all or only unsatisfactorily. In many cases, the films are thinner than the grinding gap between the grinding discs such that they pass through the grinder without being frayed. Only compacting of the two-dimensional scrap films into a three-dimensional agglomerate enables a satisfactory grinding process. A proven technology for this is the agglomeration by agitation using a pan agglomerator, which leads to the increase in a transport-optimal apparent bulk density in the form of a granular agglomerate. However, other methods for compacting scrap film into an agglomerate are also available. Thus, for example, a targeted heating, which does not exceed the melting point of the carrier film (sintering), leads to a shrinking of the flakes, which in the process are compacted into an agglomerate on their own, moved in a drum, or passed through in a discharge chute by hot air (2006, **WO2006100044** A1, CVP CLEAN VALUE PLASTICS GMBH). During the heat treatment required for the agglomeration, the thermoplastics must not be thermally damaged, i.e., they must not be heated above their type-specific melting point as, when this is exceeded, they decompose chemically with release of gases, which are harmful in most cases and cause the scrap film to become useless for technological reutilization.

Such an agglomeration of plastic particles is effected in the agglomerator known **DE2614730** A1 (1977, PALLMANN WILHELM); it refers to a polyethylene and polypropylene film disintegrator in such a way that the plastic particles fed into the disk-shaped annular chamber are gripped therein by the rotating pressing blades and are drawn into the plasticizing chambers that are formed by the inside wall of the annular perforated die and the active flank of the pressing blades and revolve with the latter. In the plasticizing chambers, the voluminous mass of particles is first pre-compacted with simultaneous venting and then plasticized within fractions of a second by the frictional heat caused by the pressing blades. Because of the shape of the blades, the plasticizing chambers in front of the rotating blades steadily narrow, and the mass is also intensively subjected to increasing thrust forces and shear forces. However, the thermoplastic mass softened in this way can then not escape through the perforated die until the pressure exerted on them by the pressing blades is sufficient to overcome the flow resistance in the die holes. When pressed through the perforated die, the thermoplastic particles, which have become tacky due to softening, are formed into compact extrudates or filaments that are cut up immediately after their emergence from the die by knives rotating on the outside wall thereof, into uniform lengths whereby uniform free-flowing granules are obtained.

US3510067 A (1970, BECK ERICH; SCHULZ HEINRICH) discloses a method and an apparatus for converting scrap film, particularly from polyethylene films, to a flowable granular material by comminuting the scrap film into small particles and thereafter densifying and agglomerating

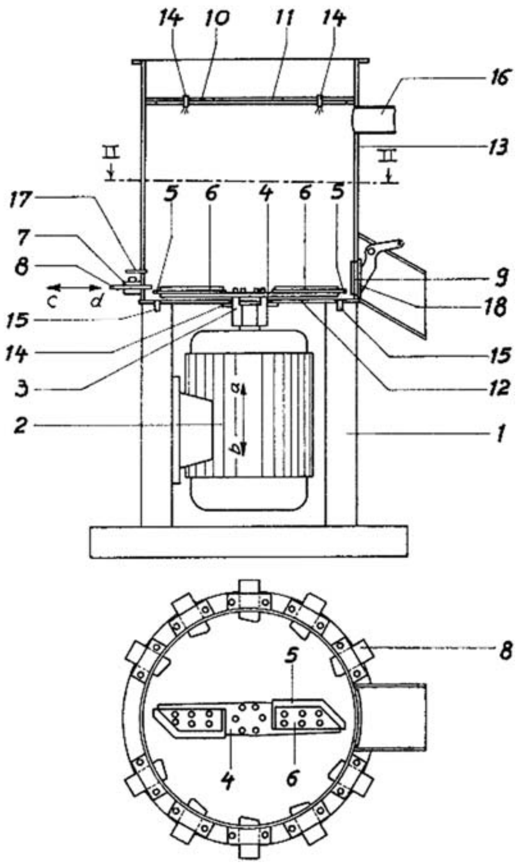

Figure 8.15 Side view of the agglomerating apparatus being taken along the line II-II (1972, **US3510067** A, BECK ERICH; SCHULZ HEINRICH). a↔b, double-headed vertical direction arrow; c↔d, double-headed horizontal direction arrow; 1, Frame structure; 2, Drive motor; 3, Hub; 4, Beater members; 5, Beater ledges; 6, Clamping plates; 7, Clamping plate; 8, Plates; 9, Outlet; 10, Cover; 11, Inlet opening of 10; 12, Bottom of the container; 13, Cylindrical container; 14, Sealing plate; 15, Nozzles; 16, Duct; 17, Thermometer; and 18, Flap.

the particles to produce granules. The apparatus, shown in Fig. 8.15, comprises a substantially cylindrical container (13) having a vertical axis (a↔b) and forming a processing chamber for receiving a batch of scrap film to be converted and the container having an inlet (11) for the scrap film and an outlet (9) for discharging the resulting granular material; beater members (4) disposed in the bottom portion (12) of the container chamber and rotatable about the axis, the beater members comprising radial beater arms axially displaceable relative to the container, and radially adjustable beater ledges (5) mounted on the respective arms; fixed comminuting members in the shape of plates, blades, or pins (8) mounted on the container and protruding inwardly into the chamber into proximity of the rotatable beater members for comminuting and granulating the scrap film in coaction with the beater members; and coolant supply means communicating with the chamber for cooling the granulated material.

Example: An apparatus was used having a cylindrical container of 1.1 m diameter and a height of 1.5 m. The beater arms extended into the immediate vicinity of the fixed comminuting plates. A quantity of 60 kg polyethylene scrap film was filled into the container. The comminution by tearing of the scrap film between beater arms and plates was effected at a peripheral speed of about 70 m/sec within about 4 min. The beater rotor was continued to be driven for an additional period of about 3 min during which most of the mechanical power supplied was converted into heat with the result that the scrap film was densified and agglomerated. During such continued running of the beater arms, about 1.5 L water of 20°C was injected for a short interval of time. After one additional minute, the solidified and cooled granular mass was discharged and was found to have no tendency to stick together.

DE1454877 B1 (1972, ULTREX CHEMIE GMBH) discloses an apparatus for the continuous granulation of flakes of scrap films. Scrap films of polypropylene or PVC are fed into the apparatus, shown in Fig. 8.16, consisting of a cutting mill (1) with a feeding equipment, a blower (7) with a feed pipeline (9), an air separator (27) and an agglomerating installation with a screw feeding device (2) manufactured according to **DE1454875** A1 (1969, ULTREX CHEMIE GMBH). The agglomerating plant is connected to a free granules discharge outlet (29) by a suction return pipe (9′), so that the granules can be separated from nongranular remnants, which are sucked back to the agglomerating installation. Variations of the apparatus can be found in **CA793191** A (1968) and **DE1454873** A1 (1970) of ULTREX CHEMIE GMBH.

8.4 Density/Gravity Techniques

Separation of different plastic materials can be performed by density/gravity sorting with a range of different technologies. The most commonly used density sorting technologies for the separation of flexible plastic

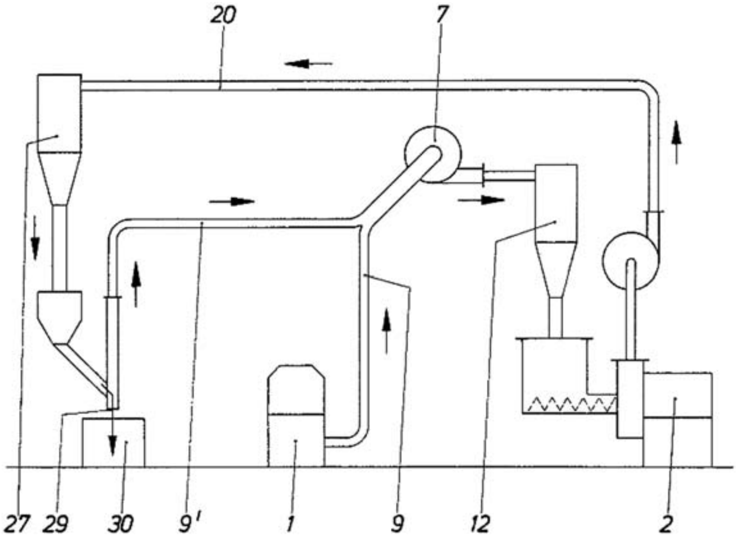

Figure 8.16 Apparatus for the continuous compressing of thermoplastic films into granules (1972, **DE1454877** B1, ULTREX CHEMIE GMBH). 1, Cutting mill; 2, Agglomerator; 7, Blower; 9, Feed pipeline; 9′, Suction return pipeline; 12, Feed hopper; 20, Feed pipeline; 27, Air separator; 29, Granules discharge outlet; and 30, Storage bin.

packaging materials are float-sink, air sifting (see Chapter 6, Section 6.1.2), and to a lesser extent, hydrocyclones and centrifuge.

Separation of different plastic phases or fractions is more difficult for mixed plastic waste because in addition to a multitude of different plastic types also composite materials and varying impurities exist in that waste. Systems for separating plastic mixtures include several float-sink stages and/or hydrocyclone stages that are successively connected. This leads to higher consumption of water and energy, whereby the losses of valuable plastic increase with each stage.

Density sorting techniques are not successful for the separation of multilayer plastic packaging materials due to the complexity of these structures.

8.4.1 Float-Sink

In the float-sink separation technique, pieces of plastic packaging shredded to predetermined sizes are immersed in a tank containing a liquid that has a density in between the constituting materials making it possible for less dense material to float and heavier to sink. Such facilities,

Table 8.1 Densities of Common Polymers and Aluminum Used in Flexible Packaging

Polymers	**Density (g/cm^3)**
Polypropylene (isotactic)	0.900–0.905
Low-density polyethylene (LDPE)	0.916–0.930
Linear low-density polyethylene (LLDPE)	0.915–0.934
Medium-density polyethylene (MDPE)	0.926–0.940
High-density polyethylene (HDPE)	0.941–0.970
Water	1.000
Nylons	1.020–1.140
Poly(vinyl chloride) (PVC)	1.290–1.440
Poly(ethylene terephthalate) (PET)	1.380–1.390
Aluminum	2.690–2.713

referred to as float-sink tanks, can separate, for example, PET, nylon, or PVC majority films with a density greater than 1.000 g/cm^3 from standard polyolefins (see Table 8.1). Typically, the density ranges of selective polyolefins are 0.900–0.905 g/cm^3 for polypropylene, 0.916–0.930 g/cm^3 for low-density polyethylene (LDPE), and 0.941–0.970 g/cm^3; for high-density polyethylene (HDPE). In contrast, the density of the aluminum foils normally used in the packaging industry ranges from 2.690 to 2.713 g/cm^3 (1993, **US5246116** A, REYNOLDS METALS CO). Float-sink tanks are critical separation tools used by film recyclers, who use a wet wash process [14].

The separation of multilayer plastic packaging materials by the float-sink technique gives often erroneous results for the following reasons: The effective density of a multilayer piece (e.g., flake or chip) depends on the ratio and the types of polymer used in a multilayer packaging material. A polyethylene, which is the main constituent of most flexible plastic packaging, is typically mixed with a number of additives and fillers, which increase the overall density of the film. When the additive/filler concentration reaches the point that the film density is greater than 1.000 g/cm^3, the film sinks in water rendering the packaging film nonrecyclable. Further, if air bubbles are attached to a surface of the PET layer with a density of 1.380 g/cm^3, or if the PET layer is positioned on a plurality of polypropylene or polyethylene (0.900−0.970 g/cm^3) films, it will float on water. If a polyolefin layer is positioned under a plurality of PET layers, it will sink in water. These mistakes can be reduced through the addition of a surfactant or through the repetition of the separation process using the specific gravity differences [15]. The separation of labels and shrink wrap sleeves from PET containers is typically achieved in float-sink tanks as part of the overall PET recycling (see Chapter 4, Section 4.2.5).

DE102008056311 A1 (2010, APK ALUMINUM UND KUNSTSTOFFE) discloses a method and an installation for separating individual valuable materials from mixed, in particular milled, plastic waste, comprising films, multilayer films and hard plastic parts, and optionally impurities. The method, outlined in Fig. 8.17, comprises the following basis steps: 1) plastic waste is separated into hard plastics and films as well as laminates; 2) the hard plastics are separated from the films; and 3) the hard plastics are separated into the different types of plastic. The hard plastics and films on the one hand and the laminated films on the other hand are separated by means of float-sink separation, and, for this purpose, the optimum density of the separation medium is adjusted by means of a measured density distribution curve of one or more fractions selected from the group consisting of the hard plastics and films and the laminated films. The films predominantly comprise LDPE, the multilayer films comprise aluminum foil and LDPE film, and the hard plastics from the lips and closure caps of drink carton rejects comprise HDPE and to a lesser extent polypropylene.

8.4.2 Hydrocyclones

Hydrocyclones can also be used for plastic film washing and separation. They serve the same purpose as float-sink tanks, where pieces of plastic films are separated from heavier contaminants, however, in a more efficient manner with a much higher separation effect, about 20 times earth's gravity.

A hydrocyclone utilizes a centrifugal force to separate pieces of plastic film according to size, shape, and gravity (specific weight). The plastic waste is fed into the hydrocyclone in a suspension. Pressure jets excel the water mixture of films and contaminants within a cylindrical apparatus. The cyclone generated pushes the lighter plastic films outward and upward, while heavier contaminants move inward and downward to the bottom of the hydrocyclone. The hydrocyclone's sensitivity and selectivity can be adjusted by choosing the nozzle sizes of the exiting outlets at both the top and the bottom.

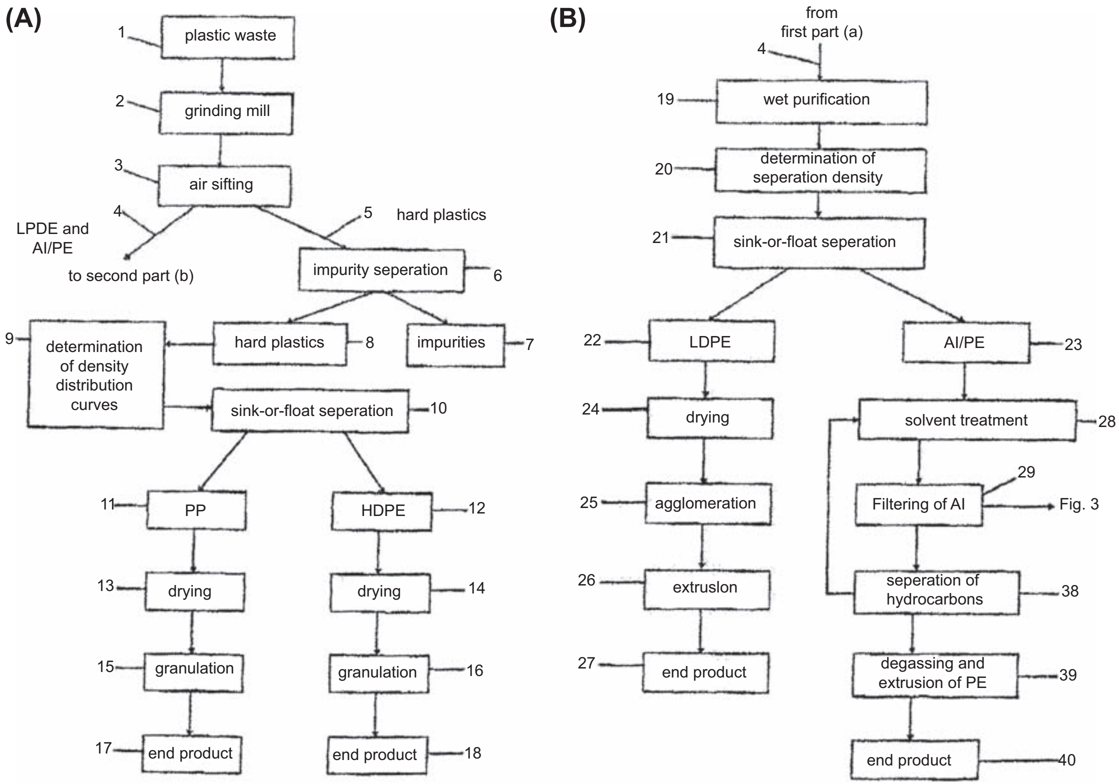

Figure 8.17 First part (A) and second part (B) of the flow diagram of the method for separation of individual materials from plastic waste comprising films, multilayer films, and hard plastics (2010, **DE102008056311** A1, APK ALUMINUM UND KUNSTSTOFFE). Al, Aluminum; HDPE, High-density polyethylene; LDPE, Low-density polyethylene; PE, Polyethylene; and PP, Polypropylene.

Heavier plastic components can be separated from the polyolefin, which is the desired material of a film washing line. A further advantage of the hydrocyclone separation step is the high amount of water present in the water circuit, ensuring together with the revolving forces arising due to the hydrocyclone a very good washing result of the films. Deposits of organic substances, a frequent feature of film from household waste, are easily removed by washing. In contrast, films from supermarkets often have a high percentage of paper in the form of affixed labels. It is a real challenge to separate this paper from the film as these linear low-density polyethylene (LLDPE) films from supermarkets are ideal as feeding material for recyclate used for the production of new film.

DE2900666 A1 (1980, BAHR ALBERT) discloses a method for the separation of mixed plastic waste composed of polymers of different densities (e.g., a mixture of granulates of polyethylene, polystyrene, and films of plasticized PVC) by reducing their size to a maximum 20 mm (preferably 5 mm long), washing, and suspending the polymers in a liquid. Successive hydrocyclones are arranged in stages, with upper cylindrical parts through which the suspended materials are dropped; the ratio of the diameter of the overflow/underflow outlets is 1−4 (preferably 1−2.5) and the ratio of the length/diameter of the top cylindrical part is 1−10 but increases with decrease in difference in density between the polymers and liquid. If the polymer's density exceeds that of the liquid, and if they are mainly plastic films, the angle of the cyclone cone is 120−180 degrees; if the density of the polymers is only partly above that of the liquid, this angle is 5−40 degrees.

According to **EP0791396** A2 (1997, DEUTZ AG), a disadvantage of the above method is the unsatisfactory separation effect, which leads to loss of solid material. Also, the required separation of the liquid from the solid matter fraction suspensions must be implemented downstream. These disadvantages are largely avoided in the separating centrifuge disclosed in **EP0553793** A2 (1993, KLOECKNER HUMBOLDT DEUTZ AG), in which the separation ensues in the generated centrifugal field of a rotating container.

EP0791396 A2 (1997, DEUTZ AG) discloses a method for the separation of mixed plastic waste containing heavy contaminants, e.g., sand or metal residues, according to their density, wherein some of the heavy impurities are separated off in a hydrocyclone (15), and the plastic mixture (e.g., polyethylene and PVC films) is separated from the rotating suspension in a following sorting centrifuge (20). The method apparatus, shown in Fig. 8.18, comprises a mixing vessel (10) for combining the solids (12) and a separating liquid (11), connected via a pump (24) to

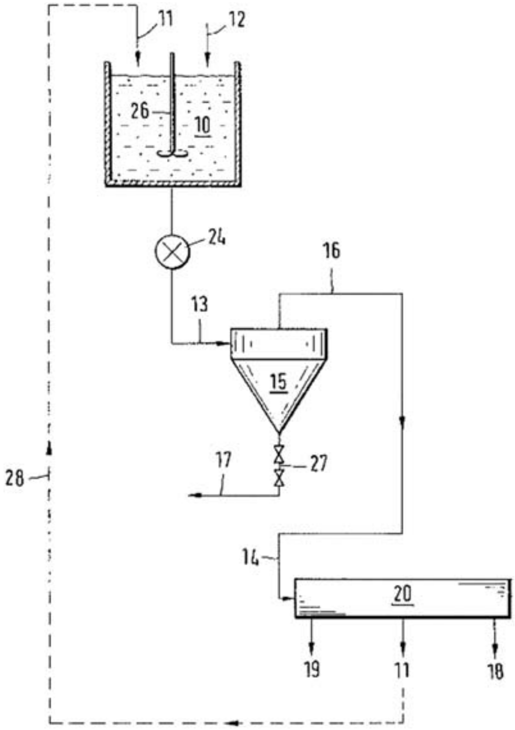

Figure 8.18 Flow diagram with direct successive connection of the hydrocyclone and the separating centrifuge (1997, **DE19606415** A1, DEUTZ AG). 10, Mixing vessel; 11, Separating liquid; 12, Solid materials; 14, Inlet; 15, Hydrocyclone; 16, Overflow; 17, Underflow,; 18, Heavy goods; 19, Light goods; 20, Sorting centrifuge; 24, Conveyor pump; 26, Mixing apparatus; 27, Sluice; and 28, Line.

a hydrocyclone (15) and a sorting centrifuge (20) whose feed (14) is connected to the overflow (16) from the hydrocyclone. Wear on components of the separating centrifuge caused by these heavy materials can be avoided, and in some applications, a second separating stage at a higher separation density can be eliminated.

Herbold Meckesheim GmbH assists its customers retrofit their film washing lines by introducing a hydrocyclone separation step in place of the common separation tank [16]. The new step improves the quality of film flakes extrusion. Herbold Meckesheim GmbH has installed a model line for Rodepa Plastics B.V. in the Netherlands that was launched at the beginning of 2018. High-quality granulate for film thicknesses lower than

30 μm is produced from a mixture of plastic waste. This mixture consists of commercial films and LDPE film waste from sorting postconsumer packaging waste as is the case with automatic waste sorting plants [16]. This plant can cope with highly contaminated films as well as with very thin gauge films. The wet shredder integrated into the washing plant and the hydrocyclone separation technology are the outstanding construction features of Herbold Meckesheim GmbH (see Fig. 8.19). To separate the contamination from the film, in the washing line as early as the presize reduction step, a wet shredder especially designed for this purpose is used with Rodepa Plastics B.V. The feeding materials consist of a mixture of different plastics.

8.5 Extrusion

The recycling of plastic films involves grinding of the films and transforming the ground material either by an agglomeration treatment in the pasty state or by twin-screw vacuum extrusion. Sometimes the ground material is obtained with equipment operating on the "Vacurema" principle (extrusion from flakes, agglomerates, or granules) using four stages of transformation integrated in the same machine:

1) compacting, sending the pasty product to the feed orifice of the screw extruder;

Figure 8.19 Hydrocyclone and dryer, in the background a prewashing unit [16]. *Courtesy of Herbold Meckesheim GmbH.*

2) transport and start of extrusion in a double-diameter single-screw extruder;
3) degassing; and
4) extrusion.

WO2010118447 A1 (2010, EREMA) discloses a method for recycling plastics comprising the following processing steps:

1) reprocessing the raw material whereby the material is comminuted, if necessary, and brought to a fluid form and then heated and permanently mixed while retaining its particulate and flowable form and, if need, be degassed, softened, dried, increased in viscosity, and/or crystallized;
2) melting the reprocessed material at least to a point where filtration is possible;
3) filtering the melt to remove impurities;
4) homogenizing the filtered melt;
5) degassing the homogenized melt; and
6) discharging and/or subsequently processing the melt, for example, by granulation or blow-extrusion treatment,whereby these processing steps are implemented consecutively and directly in chronological and spatial order without intermediate steps.

It was found to be particularly advantageous when the homogenization step is carried out after filtration, but before the degassing of the melt, as in that manner, homogenization is not negatively affected by any coarse contaminants or solid impurities or nonmolten plastic clusters, while at the same time the subsequent degassing can be carried out effectively, whereby the gas bubbles can be removed completely from the melt. In that manner, a final product of high quality can be achieved, which can be used for many different subsequent processing applications. Contaminated packaging films that were printed or had adhesive labels were processed in comparative experiments, namely once with an arrangement known from prior art without homogenization according to the conventional method and parallel to it with the inventive arrangement of the claimed method with homogenization. It was found that in the conventional method, the material is not completely degassed, but that small gas bubbles, caused by the decomposed printer inks, remain in the final product. With the claimed method, in particular through homogenization before degassing, the degassing result is further improved and hardly any gas bubbles can be seen.

Erema developed the Intarema® TVEplus® system especially for the processing of postconsumer materials [17]. Heavily contaminated film can be processed with the recycling duo Intarema® TVEplus® and Erema Laserfilter to make high-quality recyclates.

The Intarema® TVEplus® system, shown in Fig. 8.20, works as follows: Automatic feeding (1) of the material according to customer requirements. The material is cut, mixed, heated, dried, precompacted, and buffered in the cutter/compactor (2). Next, the tangentially connected extruder is filled continuously with hot, precompacted material. The patented Counter Current technology changes the direction of rotation inside the cutter/compactor and enables optimized intake action across an extended temperature range. The material is plasticized and degassed in reverse in the extruder screw (3). At the end of the plasticizing zone, the melt is directed out of the extruder, cleaned in the fully automatic, self-cleaning filter (4), and returned to the extruder again. The final homogenization of the melt (5) takes place after the melt filter. The filtered and homogenized material is degassed in the subsequent degassing zone (6). Following this, and with the help of the discharge zone (7), the melt is conveyed to the respective tool (8) (e.g., pelletizer) at extremely low pressure [17].

The patented extruder system Intarema TVEplus sets new standards in the recycling of materials that are difficult to process such as heavily printed polyethylene and polypropylene films, very moist materials (e.g., washed polyethylene film flakes), polyethylene films with paper

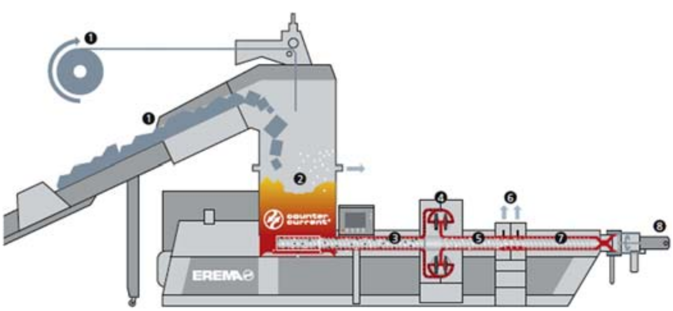

Figure 8.20 Schematic diagram of the Intarema TVEplus system [17]. 1, Feeding; 2, Cutter/compactor; 3, Extruder screw; 4, Self-cleaning filter; 5, Melt; 6, Degassing zone; 7, Discharge zone; and 8, Pelletizer. *Courtesy of EREMA.*

contamination, and metalized biaxially oriented polypropylene (BOPP) films. This is made possible through ultrafine filtration, thorough melt homogenization, and high-performance degassing in a single step.

WO2007076165 A2 (2007), **US2007120283** A1 (2007), and **US2008233413** A1 (2008) of APPLIED EXTRUSION TECHNOLOGIES disclose a method for making a multilayer film including a core layer with recycled oriented polypropylene (OPP) film therein comprising the following steps: 1) bales of OPP flexible packaging or label stock including inks either with or without an adhesive in the product are fed into a granulator where large sheets of recycled material are reduced in size to flakes of about (1/8) to (1/4) in^2; 2) the flakes are then processed through a densifier to produce compressed pellets of unmelted film; heat generated in this process is an important first step in reducing the volatiles from the inks and adhesives in the label stock; and 3) the pellets are fed into an extruder, which is equipped with a vacuum vent; vacuum venting the extruder is very important to further reduce volatiles from the inks and adhesives, as well as moisture and entrained air in the feed. A commercial processing aid, such as a compound of calcium oxide in polyethylene (e.g., ML1803, ML Plastics GmbH), is fed with the scrap at a 3 wt% level, to aid in reducing the volatiles by chemical reaction. Finally, the melt is pumped through a fine mesh filter and into a standard underwater pelletizer. In some cases, the product is directed through a fine mesh filter before vacuum venting. The pellets then are introduced into an extruder for incorporation into the core layer of a new, multilayer, opaque plastic film, either uniaxially oriented or biaxially oriented (see also Section 8.9.1).

WO2014162238 A (2014, JAIN PRANAY) discloses a method for converting waste or used metalized (aluminum coated) PET film to recycled PET pellets with enhanced physical, mechanical, optical, and aesthetic properties comprising the steps of:

1) collecting waste/used metalized PET film;
2) reducing the size of waste or used metalized PET film in flakes either before or after washing by a grinder or granulator or by cutter compactor;
3) washing the film of step (1) and/or flakes of step (2) in a hot water bath or in alkaline (e.g., caustic soda) or in alkali solution having a concentration in the range of 0.5−3 wt% in water solution at room temperature to 90°C;

4) densifying the film or flakes of step (3) in an agglomerator to increase the bulk density of the film or flakes;
5) feeding the obtained film or flakes of step (4) into an extruder for devolatilizing, homogenizing, and converting the same into melt;
6) conveying the melt of step (5) into a pelletizer to obtain recycled PET pellets having intrinsic viscosity less than 0.55 dL/g; and
7) increasing the intrinsic viscosity of the pellets obtained in step (6) from 0.55 dL/g up to 1.00 dL/g by solid-state polymerization (SSP) to obtain recycled PET pellets suitable for making high-quality strapping or monofilament yarn or sheets.

PET straps, monofilaments, yarns, or sheets were made from pellets of recycled metalized PET film.

8.6 Integrated Systems

An early study describes an integrated system for the recovery of polyolefin films from packaging and industrial wastes in the form of very clean recycled film flakes from even the dirtiest of scrap film. The feedstock is provided in form of baled film, which has had metal or plastic strapping removed, wherein the scrap film is reduced to smaller stripes in a shredder, which are carried under an electronic metal detector and then fed with other impurities into a water-filled separation tank where the polyolefin films float while the heavier fractions sink to the bottom of the separation tank for removal. The floating stream is then fed in a wet granulator where it is intensively washed. Water recycling circuits from tanks are also provided [18].

US2012199675 A1 (2012), **US2013186573** A (2013), and **US2014048631** A (2014) of WISCONSIN FILM and BAG INC disclose a method (see Fig. 8.21) and an apparatus (see Fig. 8.22) for processing a supply of postconsumer scrap LLDPE or LDPE film. The method includes tearing the supply of film in a shredder, wherein the surface area of the film is exposed, including delamination of the film. The torn supply of film is washed in a water bath including a surfactant and agitated to remove contaminants from the film. The washed film is ground into smaller pieces, and additional washing of the ground film in a rotating friction washer occurs wherein additional contaminants are removed from the film. The ground film is then dried and compacted without addition of water into granules of near-virgin quality polyetylene.

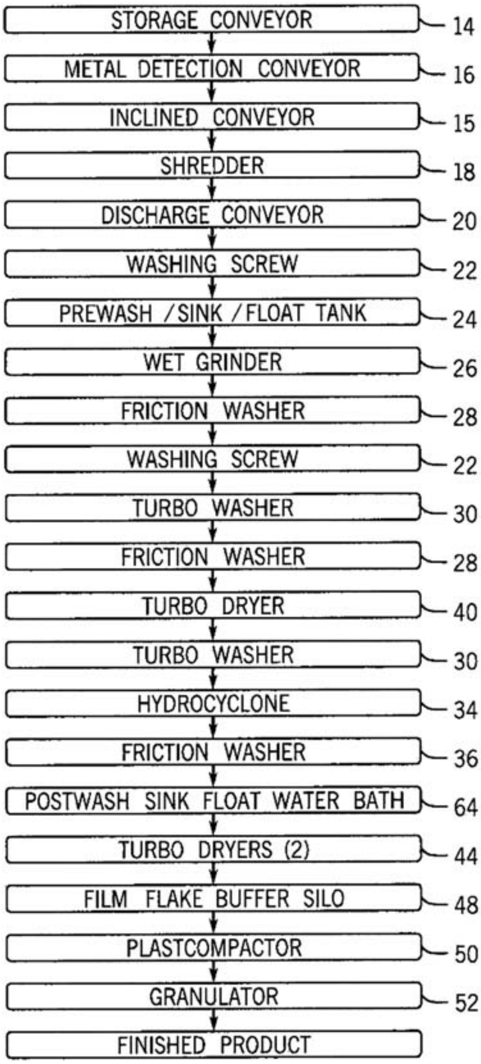

Figure 8.21 Flowchart of the method for recycling postconsumer scrap film (2014, **US2014048631** A, WISCONSIN FILM and BAG INC).

US2013119575 A1 (2013) and **US2013119171** A1 (2013) of NEXT-LIFE ENTERPRISES, LLC disclose a process (see Fig. 8.23) and an apparatus (see Fig. 8.24) for recycling plastic waste material, including shredding the waste material in a universal shredder apparatus and washing the waste material. The apparatus includes a dryer for drying substantially all moisture from the plastic, and an agglomerator that

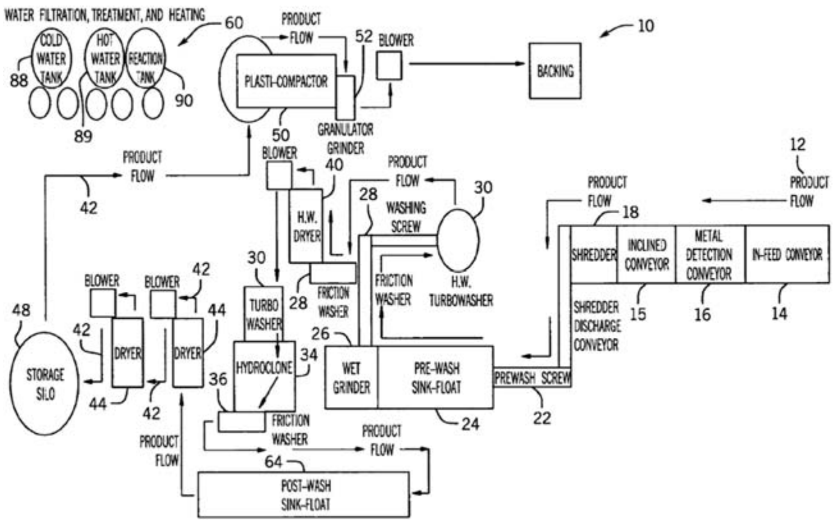

Figure 8.22 Schematic top view of an apparatus configured to process scrap film in accordance with the flowchart of Fig. 8.21 (2014, **US2014048631** A, WISCONSIN FILM and BAG INC).

receives the dry film material from the dryer and creates a course mix of cut material. Multiple in-line extruders process the cleaned plastic with filter screens positioned after each extruder to mix and filter the plastic into a final uniform mixed mass, which is sent to a pelletizer.

CN106994756 A (2017, GUANGZHOU HONGTAI PLASTIC TECH CO LTD) discloses a scrap plastic film recycling and treating apparatus. The apparatus comprises a shredder, a cooling device, a blow-drying device, a granulator, and a collecting bin. The granules can be used for producing new film.

Some representative commercial integrated film recycling systems are the following:

Sorema's film recycling process is outlined in Fig. 8.25 [19]. The first step in film recycling is generating a stable flow of the incoming waste through a shredder. Prewash then takes place, initially by agitation and decontamination and subsequently in float-sink tanks to remove heavier contaminants. This operation reduces machinery wear in the remaining part of the line. Precleaned film shreds are sent to a wet granulator followed by a centrifuge for the removal of water and pulp. A stirring and separation tank follow, for further decontamination. Additional centrifugation steps follow to remove fine contaminants and water. Specially

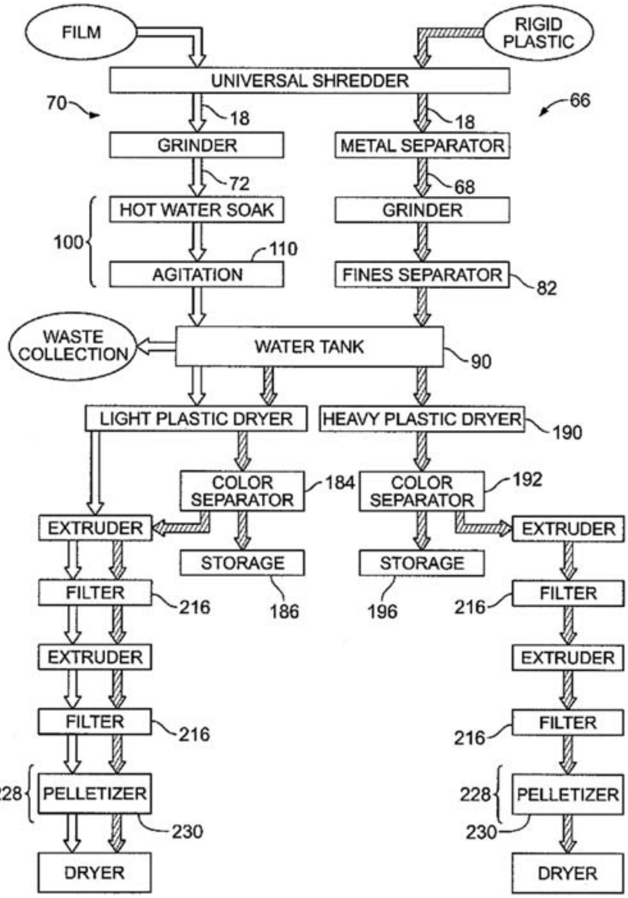

Figure 8.23 Block diagram view of the process for recycling film and rigid plastic (2013, **US2013119575** A1; 2013, **US2013119171** A1, NEXTLIFE ENTERPRISES, LLC).

designed thermal drying with hot air allows to remove efficiently final moisture.

Polystar's plastic recycling apparatus Repro-Flex is designed for the reprocessing of polyethylene (HDPE, LDPE, LLDPE) and polypropylene flexible packaging material, printed and nonprinted. This cutter-integrated pelletizing system eliminates the need of precutting the material and requires less space and energy consumption, while producing high quality plastic pellets at a productive rate [20].

The Repro-Flex plastic recycling apparatus combines cutting, extrusion, and pelletizing into one compact and efficient recycling line. The

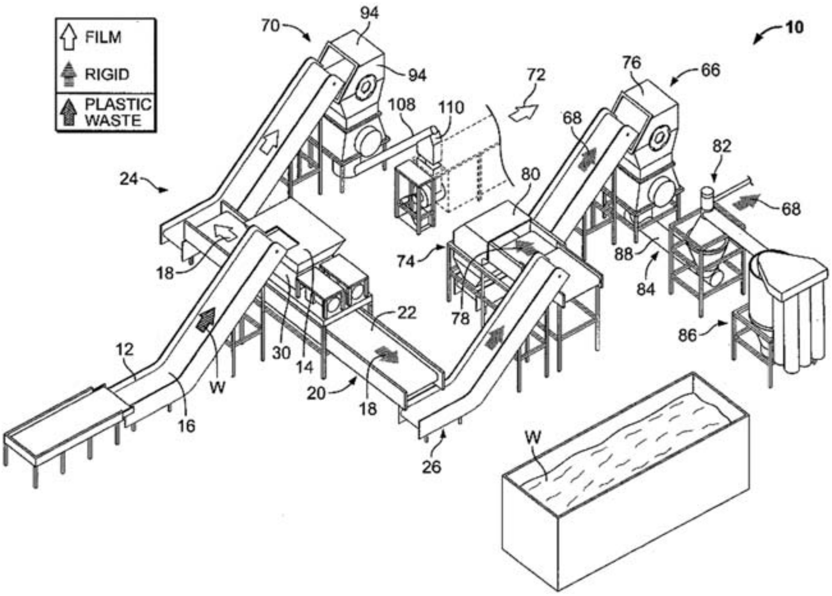

Figure 8.24 Perspective view of an apparatus depicting the initial shredding operation and the separate conveying of shredded material to a separate grinding apparatus (2013, **US2013119575** A; 2013, **US2013119171** A1, NEXTLIFE ENTERPRISES, LLC). W, Waste material; 10, Apparatus; 12, Single plastic waste intake; 14, Initial universal shredder; 16, Conveyor belt; 18, Shredded plastic material; 20, Conveyor assembly; 24, Film recycling line; 26, Rigid plastic recycling line; 30, Shredder housing; 66, Rigid processing line; 68, Rigid material; 70, Film processing line; 72, Film material; 74, Metal separation assembly; 76, Rigid material grinder; 78, Eddy current metal separation unit; 80, Ferrous metal separator; 82, Fines separator; 84, Blower assembly; 86, Fines collector; 88, Passageway; 94, Film grinder; 108, Transport duct; and 110, Agitation process.

cutter compactor of the recycling machine prepares (preconditions) the material into an ideal condition for the extrusion process and feeds the material directly into the extruder with a centrifugal force. Comparing with the conventional recycling machines, this integrated system does not require a separate crusher and, therefore, eliminates the problem of inconsistent feeding (overfeeding or insufficient feeding). The apparatus

Figure 8.25 Schematic diagram of the Sorema film recycling process [19]. 1, Feeding; 2, Primary shredding; 3, Metal separation; 4, Buffer storage; 5, Prewashing; 6, Wet grinding; 7, Final washing; 8, Mechanical drying; 9, Thermal drying and aerodynamic separation; 10, Buffer for extrusion; and 11, In-line water filtration. *Courtesy of Sorema.*

can be used for the processing of printed and nonprinted polyethylene and polypropylene monolayer and multilayer scrap film.

8.7 Blending

Blending of at least two polymers at various ratios makes possible to achieve desired property combinations of the resulting material [21]. Blending is often used to provide tailored product properties for a specific application such as barrier properties to layers in a multilayer structure. Polymer blends exhibit synergistic physical properties when the minor phase is effectively dispersed in the matrix phase (see also Chapter 3, Section 3.9). However, there are technical limitations in achieving such well-dispersed morphologies with conventional melt processing techniques. In incompatible polymer blends, a large viscosity difference and/or interfacial tension often prevents the dispersed phase from developing fine domains, and coarsening of these domains at typical processing temperatures leads to a noncompatibilized blend structure [22]. Addition of compatibilizers and prefunctionalization of the materials have yielded some success in producing well-dispersed blends; however, they are neither applicable to all polymer systems nor the most desired route of production. A continuous processing technique, called solid-state shear pulverization (SSSP) has proven to yield polymer blends with compatibilized, sub-micron-size dispersed domains [23].

Polypropylene/LLDPE chip bags can be blended with other recycled polypropylene streams to dilute the LLDPE portion. This needs not be done to simply dilute (hide) impurities in the majority polymer matrix. Sometimes, careful blends of incompatible polymers can enhance performance of the majority polymer. One drawback of polypropylene is its low impact strength, particularly, at low temperatures. If LLDPE from polypropylene/LLDPE chip bags is blended into polypropylene in a proper amount (e.g., up to about 30%), it can improve the impact strength of the polypropylene.

Henkel in cooperation with Mondi have developed a technology for incorporating more of its scrap plastic into an environmentally flexible OPP/polyethylene multilayer packaging for its laundry detergents. Henkel has begun selling its Megaperls washing powder in the resulting flexible package called “quadro seal bag” (see Fig. 8.26); 30% of the package’s polyethylene layer consists of industrial waste reclaimed from Mondi’s factory in Halle, Germany. This means that the overall structure contains about 10% regrind material. Mondi aims to achieve a 50% regranulate in the full OPP/polyethylene multilayer structure, which consists entirely of polyolefin materials [24].

8.7.1 Compatibilization

The greatest challenge in recycling multilayer plastic packaging waste is that most plastic layers are incompatible with one another, producing phase-separated mixtures with diminished properties. For years,

Figure 8.26 Henkel’s Megaperls washing powder in a flexible package called “quadro seal bag” [24]. *Courtesy of Henkel.*

a considerable amount of flexible multilayer barrier packaging films is being disposed by landfill or incineration, due to the difficulty of dispersing typical functional barrier polymers such as ethylene vinyl alcohol (EVOH) or polyamide within a more conventional polyolefin waste stream for further recycling (see also Chapter 3, Table 3.9).

8.7.1.1 Compatibilizers

A potential solution to the problem of immiscibility is through the use of compatibilizers that control the phase behavior of polymer mixtures. Flexible film converters and recyclers get value out of postindustrial packaging waste by submitting the material to a compatibility process, in which a recycling compatibilizer is added to the waste stream for further conversion of the material into pellets, allowing its reuse. However, when a postconsumer barrier film is collected and mixed with a conventional polyolefin waste stream, it is very difficult to know when to use such compatibilizers and the amounts required (2016, **EP3040199** A1, DOW GLOBAL TECHNOLOGIES LLC).

Several compatibilizers are commercially available (see Table 8.2), and, if used correctly, allow a noncompatible polymer in smaller percentage to blend with a primary polymer without negative effects.

Compatibilizers work best with polymer blends that can be processed at similar temperatures, e.g., multilayer films of polyethylene, polypropylene, and EVOH. On the other hand, for multilayer films composed of polyolefin layers and polyamide 6 (nylon 6) or PET layer having a 40−50°C difference between their processing temperatures the compatibilization is less efficient.

A drawback of the compatibilizers is that they are expensive; however, they need not be used in large quantities to be effective [3]. In general, while there are available compatibilizers capable of providing compatibilization of binary polymeric blends, such materials are specific for the blend desired. Acceptable compatibilizers for polymeric blends of three or more components simply do not exist (2002, **WO0211963** A2, MATERIAL SCIENCES CORP).

DE4223864 A1 (1994, BAYER AG) relates to polyamide mixtures containing (1) 40−98 wt% polyamide, (2) 0.5−50 wt% scrap polyamide/polyolefin film, (3) 1−50 wt% compatibilizer, and (4) 0−60 wt% normal additives. The polyolefin in (2) is polyethylene and the polyamide in (2) is nylon 6 or a copolyamide containing at least 60% caprolactam, with a weight ratio polyethylene/polyamide of (9/1)−(1/1); preferably, (2) contains 5−50 wt% polyamide. The polyamide in (1) is preferably nylon

Table 8.2 Commercial Compatibilizers for Recycling Multilayer Flexible Packaging [25]

Supplier	Commercial Name	Target Resins for Blending
Arkema	Lotader® AX8840, Lotader® AX8900	PET, PBT, PPS
Arkema	Lotader® 3210, Lotader® 3410	PA/polyolefin
Dow[a]	Retain®	PE/EVOH or PA/EVOH/PE
Dow	Intune®	PE/PP
Dow[a]	Fusabond® M603	PE/PA, PE/EVOH, PA, EVOH/PE
Dow[a]	Fusabon®d E226	PE/PA, Surlyn, EVOH, or PA
Dow[a]	Bynel® 41E710	PE/EVOH or PA/EVOH/PE
Dow[a]	Surlyn® 1650	EVOH or PA
Dow[a]	Fusabond® P353	PP/PA or PP/EVOH/PP
Dow[a]	Elvaloy® PTW, Elvaloy 3427 A C	Polyesters/PE
Struktol	Struktol® TR 219	PA, PET
Struktol	Strukto®l TR 229	PA, PC, PC/ABS

ABS, *acrylonitrile butadiene styrene;* EVOH, *ethylene vinyl alcohol;* PA, *polyamide;* PBT, *poly(butylene terephthalate);* PC, *polycarbonate;* PE, *polyethylene;* PET, *poly(ethylene terephthalate);* PP, *polypropylene;* PPS, *poly(phenylene sulfide);* Surlyn, *ionomer of ethylene acid copolymer.*
[a]*ex DuPont.*

6, nylon 66 or a copolyamide of nylon 6 and nylon 66, or a copolyamide of at least 70 wt% caprolactam. Addition of small amounts of compatibilizer (3) to mixtures of (1) and (2) gives products with impact strength at least as good as that of high-impact polyamides containing no recycled polyamide/polyolefin multilayer film. Exemplary compatibilizers (3) are copolymers of ethylene/n-butyl acrylate/glycidyl acrylate and ethylene/

acrylic acid t-butylester/acrylic acid. ''Downrecycling'' of such scrap film from food packaging therefore becomes unnecessary.

EP3040199 A1 (2016, DOW GLOBAL TECHNOLOGIES LLC) discloses a self-recyclable barrier packaging film comprising (1) at least one polyolefin layer comprising (1a) 60−94 wt% of a first component selected from the group consisting of ethylene homopolymer (e.g., DMDA-8007 NT 7 of Dow Chemical Co.), ethylene copolymer (e.g., LLDPE such as Dowlex® 5056G of Dow Chemical Co.), polypropylene homopolymer (e.g., H110-02N of Braskem), polypropylene copolymer (e.g., DS6D81 of Braskem), and combinations thereof; (1b) 0−35 wt% of a functional polymer component (e.g., Amplify® TY 1353 of Dow Chemical Co.); and (1c) 1−35 wt% of a compatibilizer component comprising an anhydride and/or carboxylic acid functionalized ethylene/α-olefin interpolymer having a melt viscosity (177°C) less than, or equal to, 200,000 mPa s (cP) and a density from 0.855 to 0.94 g/cm^3 (e.g., Retain® 3000 of Dow); (2) at least one tie layer comprising maleic-anhydride grafted polymer with a melt index of less than 50 dg/min, wherein the tie layer does not contain the compatibilizer; and (3) at least one polar layer comprising a polar polymer selected from EVOH (such as EVAL® H171B of Kuraray) or polyamide (such as nylon 6, nylon 66, and nylon 6/66 of DuPont) and combinations thereof.

JP2006298960 A (2006, NABATA and CO LTD; KANSAI KOBUNSHI KOGYO KK) discloses a low-cost reclaimed film by recycling polyethylene or polypropylene contained in wastes such as waste plastic containers and packages. The reclaimed film is obtained by adding a compatibilizer (B1) for polyethylene and polypropylene (C) to a recovered plastic mixture (A) comprising 40−60 wt% polyethylene, 40−60 wt% polypropylene, and 0−10 wt% other plastics, the total of these being 100 wt%, and subjecting the resulting mixture to inflation molding. A preferred compatibilizer is a modified polyolefin type adhesive resin of the same type as the polyolefin waste having an acid functional group (e.g., Modic™-AP 908 of Mitsubishi Chemical Corp.) or a hydrogenated block copolymer[2] (Dynaron® 6200P of JSR Co., Ltd).

KR20050005631 A (2005) and **KR100733941** B1 (2007) of KOREA INST SCI and TECH disclose a method for recycling waste aluminum-deposited multilayer packaging films comprising the steps of: 1) introducing the waste multilayer packaging films through the main hopper of a first extruder and introducing a compatibilizer through a second hopper

[2] Crystalline block−(ethylene/butylene)−crystalline block copolymer.

to conduct a first stage melting, mixing, and extrusion; 2) cooling and pulverizing the extrudate; 3) conducting a second stage melting and extrusion in a secondary extruder of the pulverized material; and 4) injection molding the secondary extrudate. The reaction temperature in the first extruder is at least 250°C and the residual time period is not less than 3 min. The waste multilayer packaging film includes a polypropylene/polyethylene-based multilayer packaging film and a nylon/polyethylene-based packaging film. The polypropylene is a highly crystalline polypropylene, and the polyethylene is LDPE or LLDPE. The waste packaging film mixture comprises 50−80 wt% polypropylene, 10−50 wt% nylon, 5−20 wt% polyethylene, 3−5 wt% polyester, and 1−2 wt% polystyrene. The compatibilizer is selected from the group consisting of a polyethylene copolymer grafted with maleic anhydride, a polypropylene copolymer grafted with maleic anhydride, a hydrogenated polystyrene−polybutadiene copolymer, a hydrogenated polystyrene-polybutadiene copolymer having maleic anhydride attached to its main chain, and a polyisoprene−polystyrene−polyisoprene triblock copolymer wherein maleic anhydride is substituted on both ends, and mixtures thereof, preferably a polyisoprene−polystyrene−polyisoprene triblock copolymer having maleic anhydride substituted at both ends thereof is used after mixing with a radical initiator.

JP2008000908 A (2008, NPO HIROSHIMA JUNKANGATA SHAKA; HIROSHIMA PREFECTURE) discloses a recycling method for the conversion of thin wall plastic products such as plastic bags by mixing the waste plastic with a modification resin, dispersing uniformly and granulating. The granulates are extruded to form new thin wall products. The waste plastics contain at least 70 wt% of both polyethylene and polypropylene as main components. The modification resin is regenerated polyethylene or polypropylene recovered from industrial waste. Heterogeneous plastics, such as polystyrene, and dissimilar materials are further added during the recycling process. A compatibilizer is further added to the modification resin to improve the compatibility between dissimilar materials and polyolefin. A preferred nonreactive compatibilizer is styrene−ethylene/butylene−styrene block copolymer, and a preferred reactive compatibilizer is maleic anhydride grafted styrene−ethylene/butylene−styrene block copolymer.

WO2015177580 A2 (2015, JÁGER INVEST KERESKEDELMI SZOLGÁLTATÓ ÉS INGATLANHASZNOSITO KFT) describes polymer blends and homogeneous polymer agglomerates containing coextruded polyolefin/polyamide packaging film waste and glass fiber reinforced plastic waste and a low molecular weight compatibilizing additive. The low molecular weight compatibilizing additive is a dicarboxylic acid anhydride, preferably maleic acid anhydride. The film waste usually contains 40–49 wt% polypropylene, 49–58 wt% polyamide, and about 2 wt% EVOH, and it is usually contaminated with prepreg or materials of pharmaceutical or food industrial sources. In one embodiment, the coextruded film is in the form of granules, and the fiber reinforced plastic is present in the form of waste SMC[3] grinds; optionally, a compatibilizing polymer such as polypropylene EPDM (ethylene–propylene–diene monomer) elastomer and a property modifying polymer such as EPDM or TPU (thermoplastic polyurethane) are used.

DE3938552 A1 (1991, DIESEN HERMANN) discloses the recycling of polyamide/polyethylene (PAPE) (50/50–99/1) film by compatibilizing the different polymer types with peroxides of formula R-O-O-R, wherein R is phenyl-aralkoxy-, aroyl-, alkoxy and/or alkyl, preferably 1,3-bis(t-butylperoxyisopropy l)benzene, and/or coagents containing preferably triple carbon bonds, such as 2-butyne-1,4-diol. The diol reacts with the secondary amine of the polyamide, and the triple bond promotes radical crosslinking with the polyethylene. The process gives a uniform melt, which can be reprocessed.

8.7.2 Solid-State Shear Pulverization

SSSP is a process in which polymer blends are sheared together at temperatures below their melting points. SSSP utilizes a modified twin-screw extruder to exert high shear forces and pressures onto a polymer blend while maintaining the solid state through continuous cooling. SSSP has proven to yield polymer blends with compatibilized, submicron-size dispersed domains. Its solid-state nature allows for morphology development to take place without regard to limitations in viscosity, thermodynamics, and kinetics. It does not require heat, monomer, solvent, or chemical premodification and, thus, is a practical and advantageous alternative for making effective polymer blends [23].

WO0211963 A2 (2002, MATERIAL SCIENCES CORP) discloses a method of making polymeric particulates (e.g., powder) from a waste stream of multicomponent scrap film comprising at least 50 wt% LDPE comprising the steps of: 1) comminuting the scrap film to chips or flakes by shredding or grinding using conventional equipment; 2) feeding the comminuted scrap film (M) to a twin-screw pulverizer (10) shown in Fig. 8.27 equipped with intermeshing pulverizer screws (14), which are

[3] Sheet molding compound.

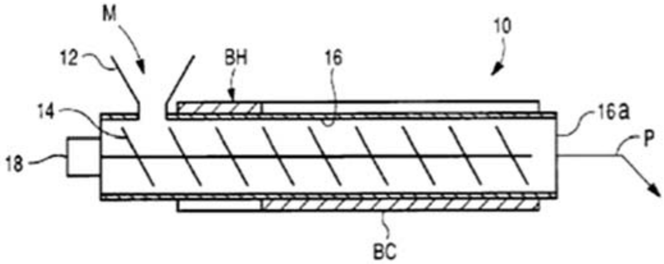

Figure 8.27 Schematic sectional view of a twin-screw pulverizer for the solid-state polymerization (SSP) of a multicomponent scrap film (2002, **WO0211963** A2, MATERIAL SCIENCES CORP). BC, Coolant bands; BH, Heating bands; M, Flake scrap material feedstock; P, Pulverized polymeric particulates; 12, Feeder; 10, Twin-screw pulverizer; 14, Intermeshing, corotating screws; 16, Pulverizer barrel; 16a, Discharge end; 18, Drive motor; and 16, Extrusion barrel.

rotated to transport the comminuted scrap film along their length, and subject it to SSSP and in situ polymer compatibilization; and 3) discharging the resulting pulverized polymeric particulates (P). Uniform pulverized particulates are produced without addition of a compatibilizing agent. The pulverized particulates (P) are directly melt processable by conventional blow molding, rotational molding, extrusion, spray coating, and other melt processing techniques requiring a powder feedstock. Scrap film containing high proportions of LDPE yield molded articles of superior notched Izod impact strength (5 ft-lb/in or 266.8 J/m) and elongation.

Zzyzx Polymers, a spinning company from Northwestern University, has developed an SSSP process known as continuous mechanochemical compatibilization (CMC), which could be used for the recycling of multilayer flexible plastic packaging. CMC differs from traditional compatibilization as it does not rely on melting. CMC cools plastics below the plastic's melting and/or glass transition temperature to maintain a solid state and then subjects them to high shear and compressive forces in a twin-screw extruder. This causes repeated fragmentation and fusion of the polymers in the solid-state leading to polymer morphology changes such as chain scission, branching, and free radical formation. Polymers are then chemically recombined, allowing compositions to bind with other polymers or fillers. Although the extruder is cooled, CMC is not an expensive cryogenic process. The plastic is processed near ambient temperature, and overall energy use remains below that for standard recycling process that requires additional washing, drying, and separation steps. Only in the final step of the process is the compatibilized powder heated so that standard plastic pellets are prepared [26]. Zzyzx Polymers' technology is based on patents **WO2014127133** A1 (2014, UNIV NORTHWESTERN) and **US2015065616** A1 (2015, ZZYZX POLYMERS LLC). In 2016, one of the inventors, Philip Brunner, left the company putting the development in jeopardy [27].

The pros and cons of Zzyzx technology can be summarized as follows:

Pros: When it comes to processing multilayer flexible packaging, the Zzyzx method compatibilizes different polymers quite effectively. It reduces impurities to particle fillers of size around 1 μm, disperses them, and eliminates air gaps between the particle fillers and the polymer(s). The result is a polymer composition with good mechanical properties. The process does not require high sortation or cleaning which reduces time, costs, and efforts. Additionally, the process is environmentally benign because it does not require monomers, solvents, or processing aids. Furthermore, unlike other solid-state processes such as ball milling, pan milling, and cryogenic milling, CMC is a continuous production process that is industrially applicable and scalable like traditional twin-screw extruder.

Cons: The application of this technology to multilayer flexible packaging still requires an understanding of the polymers within the structure. This makes collection at the curbside currently impossible [28]. Further, it is doubtful whether manufacturers of recycled polymers produced through this process would be able to offer much if any scrap value to MRFs and/or could afford to transport materials at long distances [3].

8.8 Compounding

Some reprocessors compound the recycled packaging material with additives or fillers at the reextruding phase to improve the properties of the material.

FR2870477 A1 (2005, J and M COMPOUND SOC PAR ACTION) discloses a method for recycling waste of printed polyolefin films by compounding extrusion with a mineral load. The polyolefin film waste is converted to shreds, lamellae, or flakes by grinding and densification and is then fed into a twin-screw extruder, in which addition of mineral filler or other additives takes place. The disclosed method leads to the production of a masterbatch, which is easily used in the formation of a good quality thin film having a thickness of less than 30 nm.

Example: 5 ton of production waste films, from heavily printed (over 80% of the surface) LDPE films intended for frozen food packaging, were shredded. The films were produced by coextrusion with an interior layer of LLDPE and were 50 μm thick. The films were formulated with TiO_2 to provide opacity and white background. The flakes of film had been recycled in a conventional monoscrew extruder before being introduced into the feed zone of a corotating twin-screw extruder 96 mm wide with a screw length 40 times the diameter. The mineral filler used was calcium carbonate (Omyafilm® 707) surface treated with calcium stearate. The filler was introduced into the principal extruder by two laterally mounted force feed extruders. Dosage was regulated by two gravimetric balances. The extruded product contained 50 wt% of filler introduced 60% by the first extruder and 40% by the second. The extruder speed was maintained at 380 rpm to give a final output 1200 kg/h. Irganox® 1010 was introduced as an antioxidant stabilizer. The recycled masterbatch with density 1.384 g/cm^3 was then used to produce waste sacks with an 80 mm screw diameter Kiefel® extruder, equipped with two 120 mm extruder heads. Extrusion was carried out on line with a Roll-o-Matic® double-channel sack machine. Garbage bags 700 mm wide and 950 mm long with varying thicknesses of 75−30 μm were produced. When a recycled material produced by known methods from heavily printed film with density 0.932 g/cm^3 and colored with 2 wt% dark gray colorant was used without virgin LLDPE, it was not possible to produce a film below 75 mm thick. A formulation containing 53 wt% recycled LLDPE, 25 wt% of the recycled masterbatch, 2 wt% gray colorant, and 20 wt% virgin LLDPE produced a film of 35 μm thickness.

US2015240041 A1 (2015, TORAY FILMS EUROP) discloses a method of recycling by "compounding" extrusion of metalized polyester and/or polyolefin film comprising the following stages:

1) grinding the metalized film, preferably by means of a grinding mill with metal or ceramic blades, to obtain flakes;
2) optionally, compacting the flakes resulting from grinding to form agglomerates;
3) melting the flakes or agglomerates resulting from compacting, preferably followed by filtration to remove the particles of metal and/or of at least one metal oxide, the largest dimension of which is greater than or equal to 10 μm, preferably greater than or equal to 5 μm, and even more preferably greater than or equal to 3 μm;
4) cooling/solidifying the molten mass;

5) transforming the solidified mass into discrete elements, preferably into granules;
6) manufacturing the film by melt extrusion, in which granules of a polymer (polyester, preferably PET, and/or polyolefin) and the polymer/lamellar filler obtained in stages (3), (4) and (5) are fed into an extruder;
7) cooling the obtained film; and, optionally
8) stretching the film; and
9) heat-setting the film, preferably between 180 and 250°C.

The produced films can be used for the heat treatment of various products, in particular food products, as they are extremely resistant to high temperatures (e.g., above 120°C). The heat treatments envisaged are, among others, sterilization, pasteurization, and cooking or reheating of foods in a microwave oven or steam.

CN101722639 A (2010) and **CN101857691** A (2010) of QINGDAO JIEXIN RENEWABLE RESOURCE TECHNOLOGY DEV CO LTD disclose a method for producing a recyclable composite molding from a discarded plastic/paper/aluminum flexible packaging container comprising the following steps: 1) shredding the plastic/paper/aluminum flexible packaging container into shreds of less than 10 mm in diameter; 2) adding auxiliary agents; 3) kneading the skin shreds and the auxiliary agents in the temperature range 100−125°C; 4) strengthening the kneading effect further by screw-rod shearing; and 5) extruding and molding the material by the screw rod. According to a preferred embodiment, the recyclable composite material comprises 100 Kg of pulverized packaging material; 15−45 Kg of calcium carbonate; 1−4 Kg of polyethylene wax; 0.5−2 Kg of paraffin wax; 1−3 Kg of stearic acid; and 0.2−0.3 Kg of coupling agent.

Up to date, the recycling of plastic films having a coating film, e.g., metallic, has not been used successfully in the manufacture of new films. In fact, the metalized films have increased mechanical characteristics of rigidity, and consequently, the resultant ground material is coarse (fragments with a size of about 10 μm in the plane of the coating) and quickly damages the blades of a grinder. Moreover, this coarse ground material quickly clogs the polymer filters (e.g., Vacurema of Erema) causing large production losses. Furthermore, the coarse ground material inevitably leads to film breakages on the film-making machines. Consequently, machine operating time is greatly reduced and the production costs are substantially increased. This has curtailed the recycling of metalized plastic films in film manufacture (2009, **WO2009124989** A1, TORAY PLASTICS EUROPE).

One of the well-known methods of recycling PAPE film waste is compounding it in a double-screw extruder, during which the wastes are melted, property-enhancing additives are introduced into them, and then they are "kneaded" to obtain a homogeneous material, after which the obtained material is granulated. Because of the high melting point of polyamide, this process should be performed at a temperature around 250°C; however, the processing temperature of polyolefins is only 190°C, and at temperature higher than this, polyethylene becomes highly degraded. Furthermore, any extra heat transfer step taken during the process leads to the partial degradation and property impairment of the polyethylene (2015, **WO2015177580** A2, JÁGER INVEST KERESKEDELMI SZOLGÁLTATÓ ÉS INGATLANHASZNOSITO KFT).

A composite material was produced by Tartakowski [29] from recycled five-layered PAPE, recycled polyethylene (25−75 wt%) obtained from mixed polyethylene HDPE and LDPE, and fillers in form of fly ashes (up to 30 wt%) with a particle size up to 41 μm. The PAPE film was comminuted in a knife mill with a vertical rotor and then agglomerated in a single screw extruder to obtain a regranulate (diameter 3−5 mm, length up to 5 mm). The recyclate of PAPE was modified with fly ashes, which are waste from the combustion of coal in power plants. Modification of PAPE recyclates with fly ashes increases the resistance to electric arc and improves the dimensional stability of the products, which is important especially for precision products such as sliding elements in electronic devices (e.g., bearings and electric motors).

8.9 Reuse

8.9.1 Recycled Products

DE3110254 A1 (1982, RIES WALTER) and **DE4412959** A1 (1995, RIES ANDREAS) disclose a method for the recycling of blister packaging from the pharmaceutical industry. The aluminum foil/PVC film waste is granulated in a pulverizer, for example, to grain sizes of 1.5−3 mm. The granules obtained are mixed with at least one plastic additive, for example, 50 wt% of untreated rigid-PVC granules, or waste chemical additive(s) together with waste fiber, latex and stone dust, and the mixture is used as starting material for producing thermoplastics. The aluminum/PVC film waste granules may also be added to wood chips for the production of chipboards. They may also be used as filler in mold construction for polyurethane foam molds and as filling material for adhesives in the construction industry. According to the invention, the plastic products produced by the claimed method have a high heat conductivity and a low capability, if any at all, to build up an electrostatic charge. Separate recovery of plastic and aluminum is not possible with this method.

GB2350083 A (2000, GREENAWAY HANNAH) describes a sheet material (see Fig. 8.28) produced by compression molding recycled polyethylene plastic bags. Preferably, the polyethylene bags (3) are arranged in layers, and the sheet material may be built up in successive layers, which are each subjected to heat and pressure between two heated plates (1, 4). The appearance of the sheet material may be enhanced by using dyes and/or ensuring that specific elements, e.g., of a specific color, are located on the surface when the polythene bags are arranged in their layers. The heated plates (1, 4) may be provided with a protective coating (2, 5), e.g., glass or Teflon. The produced sheets have a thickness of 1−3 mm and are colored and can be either patterned or printed. The produced sheets are claimed to be lightweight, strong, wear-resistant, durable, flexible, moldable, and are water-proof. The sheets can be used as packaging material, construction material, and as substitute for paper.

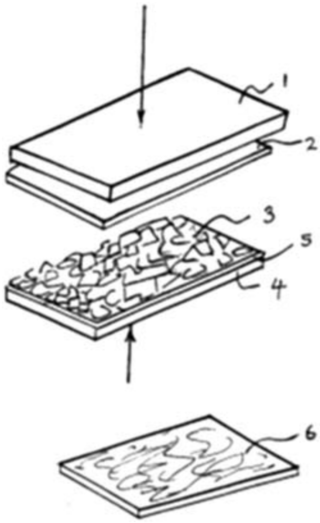

Figure 8.28 Schematic diagram of a sheet from used polyethylene bags (2000, **GB2350083** A, GREENAWAY HANNAH). 1, Heated plate; 2, Protective coating; 3, Plastic material; 4, lower plate; 5, Protective sheet; and 6, Sheet material.

JP2008213395 A (2008, NOZOE KAZUO) discloses a protective sheet made of discarded stretch films of industrial waste. The discarded stretch films are collected and pulverized, then the pulverized stretch films are heat melted and pressurized at about 200°C, and extruded in a string-like shape from an extruder. The string-like shaped plastic body is cut into pellets. The pellets are blown up by an inflation molding machine at a temperature of about 180°C. The obtained tubular body is cut and spared in one, two, or more sections along its longitudinal direction and reeled as a single sheet or one-way spread sheet. The obtained sheet is used for protecting surfaces of passages and stairways of buildings, e.g., of public institutions or factories.

WO2010066398 A1 (2010, TREOFAN GERMANY GMBH and CO KG) discloses a method for producing a BOPP film, comprising at least one layer made of virgin polypropylene and 0.5−40 wt% of OPP film−based flexible packaging and labels that have been recycled once. The film can be used as dielectric in capacitors.

WO2007076165 A2 (2007), **US2007120283** A1 (2007), and **US2008233413** A1 (2008) of APPLIED EXTRUSION TECHNOLOGIES disclose the use of recycled OPP-based flexible packaging film or label stock as part of the composition of the core layer of a multilayer opaque OPP film. The labels may be collected as scrap or second quality material subsequent to the label making process, or the labels may be separated from plastic bottles, preferably PET bottles, as part of a typical PET container recycling process. In all cases, the reclaimed material is ground up and melt extruded into pellets for inclusion into at least the core layer of a multilayer opaque film. The multilayer OPP film includes at least one skin layer containing whitening agent or other pigmenting agent therein to mask any undesired coloration created by the presence of inks and/or adhesives in the reclaimed material.

The benefits of reutilizing postconsumer OPP flexible packaging films and labels as part of the composition of a newly produced OPP film are numerous. It is envisioned that the overall economics for a process that utilizes recycled OPP film and labels would operate at a reduced material cost compared with the utilization of all new materials. The other benefits to the use of recycled OPP film and labels as part of a composition of newly produced OPP films are the environmental benefits from a recycle perspective and enhanced sustainability life cycle.

CN102909210 A (2013, HAIBO ON TO THE SDECIAL TRADE CO LTD) discloses a method for recycling discarded aluminum foil/plastic/paper packaging by combining extrusion and cold press technology in one-time molding to obtain a composite aluminum foil material product. The method comprises the following steps: 1) shredding the composite material to a particle size of 5 cm; 2) extruding the composite material at a temperature of 250−270°C for 3−4 min; 3) cold pressing the extruded material in a mold at a pressure of 25−28 MPa for 4 min so that the plastic components are wrapped on the surface of the paper and the aluminum foil. Through the above process, products such as student desks and chairs, stools, household sorting trash cans, outdoor trash cans, covers, etc., can be produced.

JP2017222425 A (2017, GREEN PLA CO LTD; DAN SANGYO KK) discloses a plastic stretch band made from a postconsumer flexible container. A postconsumer flexible container composed of polypropylene, polyethylene, and PET is shredded, melted and stretched. The obtained product is preferably composed of polypropylene in an amount of 80−90 wt% and has a melt flow index of 15 g/10 min (JIS-K7210). The composition further comprises calcium stearate, magnesium stearate, zinc stearate, calcium carbonate and talc, and/or a compatibilizing agent having affinity for at least one compound of the composition. The plastic stretch band is 0.2−0.75 mm and 0.2−0.75 wide. The plastic stretch band can be used for packing newspapers.

WO2014039479 A1 (2014) and **US2016244598** A1 (2016) of CPG INT LLC disclose a polymer composite and its method of manufacture using a recycled multilayer packaging (e.g., used beverage pouches). Examples of the recycled multilayer material comprise polyethylene/PET/aluminum film or polyethylene/polyamide/aluminum film that is extruded with an organic filler (e.g., wood flour) in an amount of 40−60 wt% to make wood-substitute products such as deck boards, railing, fencing, pergolas, residential cladding/siding, sheet products, and other applications. According to the invention, predrying the cellulosic filler and the multilayer material, using coupling agent including olefinic maleic anhydride type coupling agents such as Polybond™ of Chemtura, and/or using higher processing temperatures may facilitate the optimization of the properties of the composite (e.g., to obtain properties that are the same, similar, or improved relative to a comparable product comprising polyethylene, polypropylene, other polyolefin, or ionomer instead of recycled multilayer materials).

BRPI0804756 A2 (2010, COSMO ANTONIO EUFRASIO DE ARAUJO) discloses an asphalt pavement formed from an asphalt matrix reinforced by fragments of flexible multilayer and/or monolayer plastic packaging in an amount of 0.1−40 wt% relative to the weight of the

Figure 8.29 Asphalt pavement formed from an asphalt matrix (2) reinforced by fragments of flexible multilayer and/or monolayer plastic packaging (1) (2010, BRPI0804756 A2, COSMO ANTONIO EUFRASIO DE ARAUJO).

asphalt matrix (see Fig. 8.29). The asphalt pavement can be used in transport, architecture, engineering, urban planning, design, and related areas.

8.9.2 Commercial Uses

Currently, most recycled flexible packaging is reused in applications that are different to their initial use. The major end uses of recycled plastic films in the United States include composite lumber (43%) for applications such as decking and park benches, film/sheet, e.g., plastic bags (37%) and other uses (20%), such as containers, crates, pipes, pallets, and playground sets [30]. Composite lumber remains the dominant domestic end-use market for postconsumer plastic films [31]. In the United States and Canada, recycled film from commercial, mixed polyethylene film, and curbside film is used to produce recycled content film and sheet products such as trash bags and thicker gage commercial film. Film and sheet markets sourced about 16% of the available supply of recycled film in the United States in 2011. Additional end uses in Canada and the United States reported in 2011 were automotive applications, pipe, lawn and garden products, and some injection molding articles [1].

Multilayer films are considered contamination and are used in low-value applications such as fishing floats depending on the type of materials and volume.

The percentage of film-to-film (37%) recycling could be increased if the demand for postconsumer recycled film (PCR) is also increased. Currently, the processing capacity of PCR is lower than the amount of film that is collected. This limited capacity to process PCR film was compounded so far by the fact that Europe and the United States used to export more than 50% of its collected film to China, but China is no longer accepting this material (see Chapter 10, Section 10.3). An increased demand for PCR film will allow recyclers to invest in more advanced equipment that can produce high quality PCR to be used in more applications [32]. Turning flexible plastic packaging into other applications is a viable way to reuse flexible packaging secondary materials. Producing more recycled material from flexible packaging would intensify competition and a greater availability of products would bring down the prices [33].

TerraCycle is a US recycling company working with many of the world's best companies to bring upcycling[4] solutions to many forms of waste. They convert flexible plastic packaging waste into a range of innovative products, for example, by sewing juice pouches together into backpacks, chip bags into casual shoes, and even granola wrappers into shower curtains. Many of these products are available to buy in major retailers around the world as well as online [34].

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Patents

Patent Number	Publication Date	Family Members	Priority Numbers	Inventors	Applicants	Title
BRPI0804756 A2	20100908		BR2008PI04756 20080801	COSMO ANTONIO EUFRASIO DE ARAUJO	COSMO ANTONIO EUFRASIO DE ARAUJO	Pavimento asfáltico formado por uma matriz asfáltica reforçada por fragmentos de embalagens flexìveis multicamada e/ou monocamada e respectivo processo de fabricação. "Asphalt pavement formed from an asphalt matrix reinforced by fragments of flexible multilayer and/or monolayer packaging and respective manufacturing process."
CA793191 A	19680827		CAT793191 00000000	MERGES HERBERT A; PASTEKA JOSEF	ULTREX CHEMIE GMBH	Method and apparatus for granulating pieces of thermoplastic resin film.
CN101722639 A	20100609	CN101722639 B 20140101	CN20081158534 20081103	ZHONGHUA DOU; QIYUAN TENG	QINGDAO JIEXIN RENEWABLE RESOURCE TECHNOLOGY DEV CO LTD	Method for producing recyclable regenerative composite section with plastic paper aluminium flexible packaging box.
CN101857691 A	20101013		CN20101196464 20100610	ZHONGHUA DOU; LIGUI JIAO; QIYUAN TENG	QINGDAO JIEXIN RENEWABLE RESOURCE TECHNOLOGY DEV CO LTD	Composite reproducible material and production method thereof.
CN101954677 A	20110126	CN101954677 B 20130306	CN20101292607 20100927	ZHIPING BAO; YOUXIANG WANG; YING WANG	ZHANGJIAGANG LIANGUAN ENVIRONMENT PROT TECHNOLOGY CO LTD	Waterless cleaning device for waste plastic films.
CN102909210 A	20130206	CN102909210 B 20150617	CN201110224411 20110805	SHI ZEMING	HAIBO ON TO THE SDECIAL TRADE CO LTD	Process based on hot extrusion cold press technology for recycling waste composite aluminum foil material.
CN103240809 A	20130814		CN2012125897 20120207	FAN GUANGLIANG	NANTONG INT PLASTIC ENG CO LTD	Plastic film recovery and cleaning device.
CN103240811 A	20130814		CN20121028612 20120209	FAN GUANGLIANG	NANTONG INT PLASTIC ENG CO LTD	Improved film waste material recovery and cleaning device.

CN106426638 A	20170222		CN20161984322 20161109	YAO DONGPING	SUZHOU DEGRADATION PLASTIC MACHINERY COMPANY	Waste film recycling and cleaning process.
CN106738455 A	20170531		CN201611117347 20161207	ZENG XIUQIN	CHONGQING YAOHONG FOOD CO LTD	Plastic film recycling and cleaning mechanism.
CN106994756 A	20170801		CN201710404644 20170601	HUANG TIANGUI; HU ZHULIN	GUANGZHOU HONGTAI PLASTIC TECH CO LTD	Plastic film waste recycling and treating device.
CN201776854 U	20110330		CN20102543351U 20100927	ZHIPING BAO; YOUXIANG WANG; YING WANG	ZHANGJIAGANG LIANGUAN ENVIRONMENTAL PROT TECHNOLOGY CO LTD	Waste plastic film water-free cleaning device.
DE102008056311 A1	20100512	BRPI0921209 A2 20160223; CN102256761 A 20111123; CN102256761 B 20150930; EP2364246 A 20110914; EP2364246 B1 20161109; ES2621228 T3 20170703; US2011266377 A1 20111103; US9469049 B2 20161018; WO2010052016 A2 20100514	DE20081056311 20081107	LINDNER WOLFGANG	APK ALUMINUM UND KUNSTSTOFFE	Verfahren zum Abtrennen einzelner Wertstoffe aus gemischtem insbesondere zerkleinertem Kunststoffabfall. “Method for separating individual valuable materials from mixed, in particular milled, plastic waste."
DE1454873 A1	19700129	DE1454873 B2 19720210; CH425185 A 19661130; GB1059286 A 19670215; NL6407282 A 19641230; US3389203 A 19680618	DE1963U009924 19630629	MERGES, HERBERT; PASTEKA JOSEF	ULTREX CHEMIE GMBH	Vorrichtung zum kontinuierlichen Verdichten von thermoplastischen Kunststoffolien bzw. Kunststoffolienabfaellen "Apparatus for the continuous compressing of thermoplastic films or plastic wastes."
DE1454875 A1	19690206	DE1454875 B2 19720127	CH19640007889 19640617	A MERGES HERBERT; PASTEKA JOSEF	ULTREX CHEMIE GMBH	Verfahren und Einrichtung zum kontinuierlichen Verschmelzen von thermoplastischen Kunststoffolienabschnitten zu weiterverarbeitbaren granulatfoermigen Teilchen. "Process and apparatus for the continuous melting of thermoplastic flakes to further processable granular particles."
DE1454877 B1	19721005		DE1965U012225 19651126	PASTEKA JOSEF	ULTREX CHEMIE GMBH	Vorrichtung zum kontinuierlichen Verdichten von thermoplastischen

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Patent Number	Publication Date	Family Members	Priority Numbers	Inventors	Applicants	Title
						Kunststoffolien bzw. Kunststoffolienabfaellen. "Apparatus for the continuous compressing of thermoplastic films or plastic wastes."
DE2614730 A1	19771020	DE2614730 C2 19850404; FR2347169 A1 19771104; GB1560927 A 19800213; IT1077754 B 19850504; JPS52123448 A 19771017; JPS6235884 B2 19870804	DE19762614730 19760406	PALLMANN WILHELM	PALLMANN WILHELM	Agglomeriervorrichtung für thermoplastische Kunststoffolien. "Apparatus for agglomerating thermoplastic foil."
DE2900666 A1		DE2900666 C2 19920402	DE19792900666 19790110	BAHR ALBERT; VOGT VOLKER	BAHR ALBERT	Verfahren zum Trennen von Gemischen unterschiedlicher Kunststoffabfälle. "Method for separating mixtures of different plastic wastes."
DE29803922 U1	19980709	AT222806 T 20020915; EP0940184 A1 19990908; EP0940184 B1 20020828	DE19982003922U 19980306	HACKL HERBERT; RAWEIN ARTHUR	HOSOKAWA ALPINE AG	Einzugsvorrichtung für einen Folienzerkleinerer. "Feeder means for sheet material granulator."
DE3110254 A1	19821007		DE19813110254 19810317	RIES WALTER	RIES WALTER	Verfahren zur Verwertung von Alu-PVC Abfalllfolien der Farma industrie, und nach solchen Verfahren hergestellte Produkte. "Process for reutilising aluminium-PVC waste films from the pharmaceutical industry, and products produced according to such a process."
DE4223864 A1	19940127		DE19924223864 19920720	TIMMERMANN RALF; DUJARDIN RALF; ORTH PETER; OSTLINNING EDGAR; SCHULTE HELMUT; DHEIN ROLF	BAYER AG	Polyamidmischungen mit Polyamid/Polyolefin-Verbundfolienabfällen. "Polyamide mixtures with polyamide/polyolefin film scraps."
DE4412959 A1	19951019		DE19944412959 19940413	RIES ANDREAS	RIES ANDREAS	Verwendung von Abfallstoffen zur Herstellung von Füllstoffen von

						Kunststoffkörper in Form von Estrichplatten bezw. Platten für jewede Verwendung asl unbrennbare A-Klasse. "Use of waste for the preparation of fillers of plastics in form of screed plates or plates for any use as non-inflammable A-class."
DE3938552 A1	19910523		DE19893938552 19891121	DIESEN HERMANN	DIESEN HERMANN	Coagentien und Verfahren, sovie dessen Anwendung zur chemischen Verbindung von polyethylene und Polyamid und gleichzeitiger Einstellung des Meltindex. “Coagents and process, as well their use for the chemical crosslinking of polyethylene and polyamide with simultaneous setting of the metlindex."
EP0553793 A2	19930804	AT137996 T 19960615; DE4208104 A1 19930805; DK0553793 T3 19960819; EP0553793 A3 19930901; EP0553793 B1 19960515; ES2087579 T3 19960716; JP3398786 B2 20030421; JPH06178948 A 19940628; US5342281 A 19940830	DE19924202778 19920131; DE19924208104 19920313	UNKELBACH KARL-HEINZ; ARHELGER GUNTHER-BUETTNER ROLF	KLOECKNER HUMBOLDT DEUTZ AG	Apparatus and method for the wet-mechanical treatment of solids.
EP0791396 A2	19970827	AT205750 T 20011015; DE19606415 A1 19970828; EP0791396 B1 20010919; JPH11574 A 19990106; US5948276 A 19990907	DE1996106415 19960221	NEUREITHER JOCHEN; UNKELBACH KARL-HEINZ	DEUTZ AG	Effektive Kunststoffsortierung. "Effective sorting of plastics."
EP3040199 A1	20160706	AR103165 A1 20170419; CN107107581 A 20170829; EP3040199 B1 20171004; ES2653722 T3 20180208; JP2018502743 A 20180201; US2017348950 A1 20171207; WO2016109023 A1 20160707	EP20140382589 20141231	PARKINSON SHAUN; ONER-DELIORMANLI DIDEM; CHIRINOS CAROLINA; WALTHER BRIAN W	DOW GLOBAL TECHNOLOGIES LLC	Self-recyclable barrier packaging.
EP3059061 A1	20160824	DE102015102471 A1 20160825; EP3059061 B1 20170719	DE201510102471 20150220	PERICK MATTHIAS		Verfahren zur Wiederverwertung von

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Patent Number	Publication Date	Family Members	Priority Numbers	Inventors	Applicants	Title
					MONDI CONSUMER PACKAGING TECHNOLOGIES GMBH	Kunststoff aus einem Folienverpackungsbeutel, Folienverpackungsbeutel, sowie Folienverbundbahn zur Herstellung eines Folienverpackungsbeutels. "Method for recycling plastics from a film packaging bag, a film packaging bag, and a composite film for making a film packaging bag."
FR2870477 A1	20051125	EP1791898 A1 20070606; FR2870477 B1 20060818; WO2005121231 A1 20051222;	FR20040005446 20040519	GRANGE HENRI; SCHAEFFER GERARD	J and M COUMPOUND SOC PAR ACTION	Procédé de recyclage par extrusion compoundage de déchets de films polyoléfiniques compris ceux fortenement imprimés. "Method for recycling the waste of printed polyolefinic films by compounding extrusion."
GB2350083 A	20001122	GB2350083 B 20040331	GB19990009629 19990427	GREENAWAY HANNAH	GREENAWAY HANNAH	Sheet material made from recycled plastic.
JP2003320264 A	20031111		JP20020131608 20020507	MASE TAKAO	KANEMIYA KK	Automatic sorting/processing device of a packaged food.
JP2005058845 A	20050310	JP4183178 B2 20081119	JP20030208113 20030820	MASE TAKAO	KANEMIYA KK	Washing device for packaging material.
JP2006298960 A	20061102		JP20050118067 20050415	WATANABE NORIYUKI	NABATA and CO LTD; KANSAI KOBUNSHI KOGYO KK	Reclaimed film and method for producing the same.
JP2008000908 A	20080110	JP4817983B B2 20111116	JP20060170104 20060620	NISHIJIMA WATARU; NAKATSUKA KENICHI; TSUKAWAKI SATOSHI	NPO HIROSHIMA JUNKANGATA SHAKA; HIROSHIMA PREFECTURE	Recycling method of waste plastic to thin-walled product.
JP2008213395 A	20080918		JP20070056836 20070307	NOZOE KAZUO	NOZOE KAZUO	Production process of curing sheet.

JP2017222425 A	20171221		JP20170131388 20170704	SAKON YUICHI; IDE YASUTAKA; SAKANIWA SADAO	GREEN PLA CO LTD; DAN SANGYO KK	Band for packaging produced by flexible container.
KR100733941 B1	20070625		KR20060027716 20060328	HONG SOON MAN; HWANG SEUNG SANGNAM YOUNG WAN; CHO BONG GYOO; BACK SUNG KI	KOREA INST SCI and TECH	Method for recycling of waste-packaging films vaporized with aluminum.
KR20050005631 A	20050114	KR100526722 B1 20051109	KR20030045588 20030707	HONG SOON MAN; HWANG SEUNG SANG; JEON BYEONG HWAN; KIM JUNG AHN; KIM KWANG UNG	KOREA INST SCI and TECH	Process for recycling aluminum deposited multilayer packing film waste, molding composition comprising the same and molded article from the same.
PL406201 A1	20150608		PL20130406201 20131125	KUTA PAWEŁ; KUTA LESZEK; ŻMIJEWSKI TOMASZ; MAJCHER MONIKA	KUTA PAWEŁ; KUTA LESZEK; ŻMIJEWSKI TOMASZ; MAJCHER MONIKA	Method for washing thin foils of plastic and set of equipment for the recycling washing of thin foils.
PL414258 A1	20170410		PL20150414258 20151003	SZMIDT JACEK; KRASIŃSKI GRZEGORZ	POLIMER COMPOMAX PRZEDSIĘ-BIORSTWO PRODUKCJI PREFABRYKATÓW KOMPOZYTOWYCH SPÓŁKA Z OGRANIC	Method for utilization of polyolefins from municipal wastes, preferably polyethylene and the polyethylene composites with low density for the production of utility elements.
RU2116196 C1	19980727		RU19960107939 19960419	PANOV ALEKSANDR KONSTANTINOVIC; BIKTIMIROV FARIT VAGIZOVICH; PETROV PAVEL IVANOVICH; IBRAKOV MINNULA SHAJAKHMETOVIC; SHULAEV NIKOLAJ SERGEEVICH; BELOBORODOVA TAT JANA GENNAD E	PANOV ALEKSANDR KONSTANTINOVIC; BIKTIMIROV FARIT VAGIZOVICH; PETROV PAVEL IVANOVICH; IBRAKOV MINNULA SHAJAKHMETOVIC; SHULAEV NIKOLAJ SERGEEVICH; BELOBORODOVA TAT JANA GENNAD E	Plastic waste disintegration apparatus.
US2008233413 A1	20080925		US20080105343 20080418; US20060550611 20061018; US20050727726P 20051018	HOSTETTER BARRY JASON; WELCH PHILIP F	APPLIED EXTRUSION TECHNOLOGIES	Polypropylene films employing recycled commercially used polypropylene based films and labels.

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Patent Number	Publication Date	Family Members	Priority Numbers	Inventors	Applicants	Title
US2012160282 A1	20120628	JP2012139838 A 20120726; JP5774304 B2 20150909	JP20100292355 20101228	HASEGAWA TOSHIHIRO	HASEGAWA TOSHIHIRO	Apparatus for washing resin mold.
US2012199675 A1	20120809	CA2764077 A1 20120809; CA2764077 C 20160412; MX2012001752 A 20120831; US10022725 B2 20180717; US2014014749 A1 20140116; US2014209716 A1 20140731; US2014209725 A1 20140731; US2015367535 A1 20151224; US2017072595 A1 20170316; US8567702 B2 20131029; US8690090 B2 20140408; US9114551 B2 20150825; US9114552 B2 20150825; US9527223 B2 20161227	US201113024088 20110209	KULESA ROBERT FRANCIS; FEENEY JAMES J; CARLSTEDT RICHARD WAYNE; BLAKE DANIEL WILLIAM; HACKER BUCKELL GARY	WISCONSIN FILM and BAG INC	Post-consumer scrap film recycling process.
US2012325950 A1	2012227	CA2775435 A1 20121224; EP2537588 A2 20121226; EP2537588 A3 20150805; EP2537588 B1 20160406; ES2572650 T3 20160601; US9144803 B2 20150929	US201113168265 20110624	DAVIS ROSWELL; KAISER STEFAN; KOLBET GARY	VECOPLAN LLC	Shredder with multi-point cutters.
US2013119171 A1	20130516		US201113294893 20111111	WHALEY RONALD LEE; SHAH ANILKUMAR RASIKLAL; ZHAO HUIMIN	NEXTLIFE ENTERPRISES LLC	Plastic waste recycling apparatus and system.
US2013119575 A1	20130516		US201213623518 20120920; US201113294893 20111111	WHALEY RONALD LEE; SHAH ANILKUMAR RASIKLAL; ZHAO HUIMIN	NEXTLIFE ENTERPRISES, LLC	Plastic waste recycling apparatus and system.
US2013186573 A1	20130725	US8820666 B2 20140902	US201313796143 20130312; US201113024088 20110209	KULESA ROBERT FRANCIS; FEENEY JAMES; CARLSTEDT RICHARD WAYNE; BLAKE DANIEL WILLIAM;	WISCONSIN FILM and BAG INC	Post-consumer scrap film recycling process.

				HACKER BUCKELL GARY; JOHNSON ABBY MARIE		
US2014048631 A1	20140220	CA2900848 A1 20141002; CN105189075 A 20151223; CN105189075 B 20171031; EP2969443 A1 20160120; EP2969443 A4 20161019; EP2969443 B1 20180221; HK1220665 A1 20170512; JP2016522099 A 20160728; MX2015011162 A 20151111; US2015375425 A1 20151231; US2016236377 A1 20160818; US2018065276 A1 20180308; US9120104 B2 20150901; US9138749 B2 20150922; US9346192 B2 20160524; WO2014158316 A1 20141002	US201313796143 20130312; US201314063045 20131025	KULESA ROBERT FRANCIS; FEENEY JAMES J; CARLSTEDT RICHARD WAYNE; BLAKE DANIEL WILLIAM; HACKER BUCKELL GARY	WISCONSIN FILM and BAG INC	Post-consumer scrap film recycling process and system.
US2015065616 A1	20150305	US9296882 B2 20160329; WO2015034889 A2 20150312; WO2015034889 A3 20151105	US201361873790P 20130904	BRUNNER PHILIP; TAPSAK MARK; JANSE MICHAEL	ZZYZX POLYMERS LLC	Methods for increasing throughput rates of solid-state extrusion devices.
US2016244598 A1	20160825	US9976018 B2 20180522	US201615146113 20160504; US201514830823 20150820; US201314017503 20130904; US201261696476P 20120904	STANHOPE BRUCE; ZEHNER BURCH E; BUHRTS BRYAN K	CPG INT LLC	Use of recycled packaging in polymer composite products.
US2017253891 A1	20170907		US201715597075 20170516; US201414160020 20140121; US201213352119 20120117; US201113013707 20110125; US201414587846 2014123 US201414231291 20140331; US201213693763 20121204; US201113221647 20110830; US201514746172 20150622; US201313794214 20130311; US20100897996 20101005; US201213612037 20120912; US201414181718 20140216; US20100298208P 20100125; US20100417216P 20101124; US20090291177P 20091230;	GITSCHEL GEORGE	ORGANIC ENERGY CORP	Systems and methods for processing mixed solid waste.

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Patent Number	Publication Date	Family Members	Priority Numbers	Inventors	Applicants	Title
			US201161533528P 20110912; US201361765723P 20130216			
US3510067 A	19700505	GB1190395 A 19700506; SE315387 B 19690929; US3685748 A 19720822	DE1966F050106 19660902; DE1967F053207 19670811	BECK ERICH; SCHULZ HEINRICH	BECK ERICH; SCHULZ HEINRICH	Method and device for converting thermoplastic foil waste to a flowable granular material.
US3545686 A	19701208	US3545686 X6 19701208	US19680713533 19680315	DUPONT	BROWN GEORGE NELSON	Shredder.
US4738404 A	19880419	AU1242588 A 19880824; CA1295594 C 19920211; CN1004859 B 19890726; CN88100480 A 19880817; EP0344198 A1 19891206; EP0344198 B1 19911127; ES2009525 A6 19891001; JPH01503213 A 19891102; KR900008673 B1 19901126; MX159798 A 19890830; WO8805695 A1 19880811	US19870010048 19870202	MITCHELL WAYNE R	SPROUT-BAUER INC ANDRITZ	Rotary knife cutter having roll-off cover.
US5170949 A	19921512	AU1825892 A 19930218; AU643145 B2 19931104; CA2069771 A1 19930217; CA2069771 C 19960416; CN1069675 A 19930310; CN1025161 C 19940629; EP0528184 A1 19930224; JPH05277464 A 19931026; KR950010976 B1 19950926; MX9204733 A 19930701; US5307998 A 19940503	US19910746357 19910816	BUCK RAY A; SMITH KIMBER; WILSON LARRY J	SPROUT BAUER, INC ANDRITZ	Apparatus and method for processing scrap film.
US5246116 A	19930921	AT149381 T 19970315; CA2106511 A1 19940323; EP0589672 A2 19940330; EP0589672 A3 19940504; EP0589672 B1 19970305	US19920948525 19920922	KIRK THOMAS E	REYNOLDS METALS CO	Method and apparatus for separation and recovery of the components from foil-containing laminates.

US5257740 A	19931102	TW221391 B 19940301; US5257740 X6 19931102; WO9407672 A1 19940414	US19920953660 19920929	PREW STANLEY R; SEKSINSKY MARK J	SPROUT BAUER INC ANDRITZ	Apparatus and process for recycling scrap film.
US5285973 A	19940215		US19920914155 19920715	GOFORTH BILLY D; GOFORTH CHARLES L; BROOKS JOE G; BROOKS J DOUGLA	ADVANCED ENVIRONMENTAL RECYCLING TECHNOLOGIES, INC	Close tolerance shredder.
US9713812 B1	20170725		US201213612037 20120912; US201161533528P 20110912	GITSCHEL GEORGE	ORGANIC ENERGY CORP	Methods and systems for separating and recovering recyclables using a comminution device.
WO0211963 A2	20020214	AU8716301 A 20020218; CA2418955 A1 20020214; EP1313600 A2 20030528; US2003078367 A1 20030424; US6494390 B1 20021217; WO0211963 A3 20021031	US20000635673 20000810	KHAIT KLEMENTINA; RIDDICK ERIN G	MATERIAL SCIENCES CORP	Solid state shear pulverization of multicomponent polymeric waste.
WO2006100044 A1	20060928	AT410283 T 20081015; BRPI0609465 A2 20100413; CA2602528 A1 20060928; CN101151131 A 20080326; CN101151131 B 20150422; DE102005013693 A1 20060928; DK1868786 T3 20090216; EA012098 B1 20090828; EA200701972 A1 20080428; EP1868786 A1 20071226; EP1868786 B1 20081008; EP1868786 B9 20090610; ES2316055 T3 20090401; HRP20080683 T3 20090228; HRP20080683 T5 20091130; JP2008532762 A 20080821; KR20070112471 A 20071126; MX2007011647 A 20071120; PT1868786 E 20090116; US7757974 B2 20100720 US2008191069 A1 20080814		HOFMANN MICHAEL; FEDDERN ALEXANDER; LOFFLER JENS-MARTIN	CVP CLEAN VALUE PLASTICS GMBH	Verfahren und Anlage zur Zerkleinerung und Reinigung von Abfallkunststoff. "Method and apparatus for comminuting and cleaning of waste plastic."

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Patent Number	Publication Date	Family Members	Priority Numbers	Inventors	Applicants	Title
WO2007076165 A2	20070705	CA2626650 A1 20070705; US2007120283 A1 20070531; WO2007076165 A3 20080110	US20060550611 20061018; US20050727726P 20051018	HOSTETTER BARRY JASON; WELCH PHILIP F	APPLIED EXTRUSION TECHNOLOGIES	Polypropylene films employing recycled commercially used polypropylene based films and labels.
WO2009124989 A1	20091015	EP2268468 A1 20110105; EP2268468 B1 20160914; FR2929948 A1 20091016; FR2929948 B1 20100924; US2011244206 A1 20111006; US2015240041 A1 20150827; US2018079878 A1 20180322	FR20080052394 20080409	Penache MARIA CRISTINA; MARZE ALAIN JEAN-MARIE; Lacrampe VALERIE; MAITRE ERIC JEAN; CASATI PIERRE	Toray Plastics Europe	Film plastique extrudé chargé en particules metalliques, procédeé d'obtention et utilisations dudit film. "Extruded plastic film filled with metal particles, method of obtaining same and uses of said film."
WO2010066398 A1	20100617	BRPI0922267 A2 20160802; CN102245363 A 20111116; CN102245363 B 20150506; EP2376265 A1 20111019; JP2012511446 A 20120524; JP2015143029 A 20150806; JP5726746 B2 20150603; KR101807191 B1 20171208; KR20110128783 A 20111130; MX2011005987 A 20110915; RU2011128394 A 20130120; RU2480330 C2 20130427; US2011236702 A1 20110929; US2014370312 A1 20141218; US8980144 B2 20150317	DE20081061504 20081210	BUSCH DETLEF; EIDEN HARALD; PETERS CHRISTIAN; SCHAAN JOSEF	Treofan Germany GMBH and CO KG	Verfahren zur Herstellung von Polypropylenfolien. "Method for producing polypropylene films."
WO2010118447 A1	20101021	AT508951 A1 20110515; AT508951 B1 20120315; AU2010237585 A1 20111103; AU2010237585 B2 20140911; BRPI1014685 A2 20160412; CA2756733 A1 20101021; CA2756733 C 20171010; CN102395456 A 20120328; CN102395456 B 20140820; DK2419255 T3 20150413; EP2419255 A1 20120222; EP2419255 B1 20141231;	AT20090000599 20090417	FEICHTINGER KLAUS; HACKL MANFRED; WENDELIN GERHARD	EREMA	Verfahren zur Recyclierung von Kunststoffen. "Method for recycling plastic materials."

		EP2853374 A1 20150401; EP2853374 B1 20180117; ES2530728 T3 20150305; ES2663276 T3 20180411; HUE038728 T2 20181128; JP2012523970 A 20121011; JP5463411 B2 20140409; KR101448824 B1 20141008; KR20120014155 A 20120216; MX2011010726 A 20111024; PL2853374 T3 20180731; PT2419255 E 20150408; PT2853374 T 20180423; RU2011146552 A 20130527; RU2519157 C2 SI2419255 T1 20150430 UA102746 C2 20130812; US2012091609 A1 20120419; US2015239154 A1 20150827; US9808963 B2 20171107; US9821492 B2 20171121				
WO2014039479 A1	20140313	US2014061967 A1 20140306; US2015353691 A1 20151210; US2018201742 A1 20180719; US2018201743 A1 20180719; US9951191 B2 20180424	US201261696476P 20120904	STANHOPE BRUCE; ZEHNER BURCH E; BUHRTS BRYAN K	CPG INT LLC	Use of recycled packaging in polymer composite products.
WO2014127133 A1	20140821	US2015051339 A1 20150219	US201361764384P 20130213	BRUNNER PHILIP J; TORKELSON JOHN M; WAKABAYASHI KATSUYUKI	UNIV NORTHWESTERN	Method for processing polymers and/or polymer blends from virgin and/or recycled materials via solid-state/melt extrusion.
WO2014162238 A2	20141009	US2016039992 A1 20160211; WO2014162238 A3 20150402	IN2012DEL3342 20130331	JAIN PRANAY	JAIN PRANAY	A process for recycling a metalized polyester film.
WO2015177580 A2	20151126	CA2949927 A1 20151126; EP3145995 A 20170329 EP3145995 A4 20180214; HU1400262 A2 20151130; US2017174883 A1 20170622; WO2015177580 A3 20160428	HU20140000262 20140523	CSATÁRI LÁSZLÓ	JÁGER INVEST KERESKEDELMI SZOLGÁLTATÓ ÉS INGATLANHASZNOSITO KFT	Polymer blend and polymer agglomerate containing recycled multilayer film waste and fiber reinforced plastic waste and process for preparing said agglomerate.
WO9407671 A1	19940414	TW221392 B 19940301	US19920953473 19920929	PREW STANLEY R	SPROUT BAUER INC ANDRITZ	Apparatus and process for washing and shredding film.