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Clark

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(54) **SYSTEMS AND METHODS FOR MANUFACTURING BULKED CONTINUOUS FILAMENT**

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(51) **Int. Cl.**

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B29D 99/00 (2010.01)

(Continued)

(52) **U.S. Cl.**

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,938,924 A		2/1976	Abella et al.	
4,172,477 A	*	10/1979	Reich	F04F 9/04 141/65

(Continued)

FOREIGN PATENT DOCUMENTS

CN	202007825 U	12/2011
CN	202072825 U	12/2011

(Continued)

OTHER PUBLICATIONS

Gneuss, Multi Rotation System Extruder Leads to Breakthrough in Polymer Evacuation, Journal, Feb. 1, 2008, pp. 40-41, vol. 23, Nol. 1, International Fiber Journal, International Media Group, Charlotte, North Carolina, United States.

(Continued)

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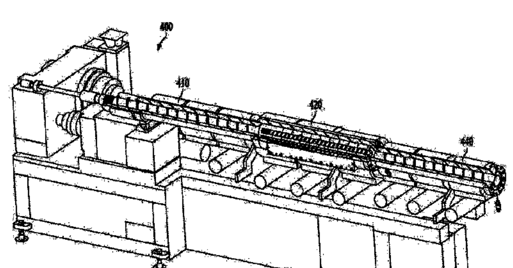
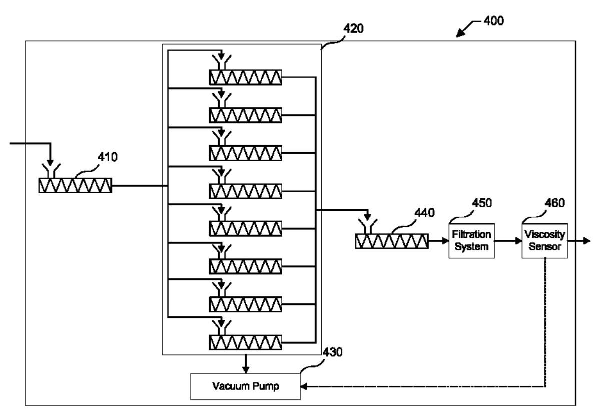
(57) **ABSTRACT**

A method of manufacturing bulked continuous carpet filament which, in various embodiments, comprises: (A) grinding recycled PET bottles into a group of flakes; (B) washing the flakes; (C) identifying and removing impurities, including impure flakes, from the group of flakes; (D) passing the group of flakes through an MRS extruder while maintaining the pressure within the MRS portion of the MRS extruder below about 1.5 millibars; (E) passing the resulting polymer melt through at least one filter having a micron rating of less than about 50 microns; and (F) forming the recycled polymer into bulked continuous carpet filament that consists essentially of recycled PET.

21 Claims, 5 Drawing Sheets





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D01D 1/10	(2006.01)
D01F 6/62	(2006.01)
B29C 47/36	(2006.01)
B29C 47/50	(2006.01)
B29C 47/92	(2006.01)
B29B 17/00	(2006.01)

(52) **U.S. Cl.**
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(56) **References Cited**

U.S. PATENT DOCUMENTS

4,370,302	A		1/1983	Suzuoka	
5,108,711	A		4/1992	Chszaniecki	
5,424,013	A		6/1995	Lieberman	
5,427,881	A	*	6/1995	Sacripante	G03G 9/08768 430/109.4
5,497,562	A		3/1996	Pikus	
5,503,788	A		4/1996	Lazareck et al.	
5,510,073	A		4/1996	Kaegi	
5,623,012	A		4/1997	Hwo	
5,886,058	A		3/1999	Van Erden et al.	
5,893,702	A	*	4/1999	Conrad	F04D 19/046 415/71
5,932,691	A		8/1999	Khanin	
6,265,533	B1		7/2001	Regel	
6,492,485	B1	*	12/2002	Gohr	B29C 47/92 264/176.1
6,784,214	B1		8/2004	Bacher	
7,485,685	B2	*	2/2009	Mihan	C08F 210/16 264/464
7,513,677	B2	†	4/2009	Gneuss	
8,557,155	B2		10/2013	Deiss et al.	
8,597,553	B1	*	12/2013	Clark	B29D 99/0078 264/101
8,735,457	B2		5/2014	Booth et al.	
8,741,972	B2		6/2014	Booth et al.	
2002/0036361	A1		3/2002	Borer et al.	
2002/0086077	A1		7/2002	Noller et al.	
2004/0072920	A1	*	4/2004	Goedicke	B29C 47/42 521/48
2005/0047267	A1	*	3/2005	Gneuss	B29C 47/767 366/83
2005/0062186	A1	*	3/2005	Fellinger	B29B 9/16 264/102
2005/0105382	A1		5/2005	Sturm	
2006/0069199	A1	*	3/2006	Charati	B82Y 10/00 524/496
2007/0200269	A1		8/2007	Ichikawa et al.	
2007/0261777	A1		11/2007	Steckelberg et al.	
2008/0069916	A1		3/2008	Regalia	
2008/0157425	A1		7/2008	Rodgers et al.	
2008/0224341	A1	*	9/2008	Portier	B29C 45/0013 264/40.1
2009/0039542	A1		2/2009	Morton-Finger	
2009/0115091	A1	*	5/2009	Eloo	B29B 9/06 264/141
2010/0102475	A1		4/2010	Moon	
2010/0152309	A1		6/2010	Booth et al.	
2010/0152311	A1		6/2010	Booth	
2010/0267914	A1	*	10/2010	Westwood	B32B 5/02 526/348
2011/0177823	A1		7/2011	Miao et al.	
2011/0257345	A1		10/2011	Hoover, Jr. et al.	
2012/0070615	A1	*	3/2012	Shi	B29C 47/6056 428/143
2013/0320581	A1		12/2013	Clark	
2014/0225293	A1		8/2014	Clark	
2015/0069652	A1	*	3/2015	Clark	B29C 47/0014 264/143
2015/0069655	A1	*	3/2015	Clark	B29C 47/0014 264/176.1
2015/0076725	A1	*	3/2015	Clark	B29B 17/0026 264/40.1
2015/0076744	A1	*	3/2015	Clark	B29B 17/0026 264/476

FOREIGN PATENT DOCUMENTS

CN	2020072825	U		12/2011
DE	19722278	A1	†	12/1998
DE	2008018686	A1		10/2009
DE	102008018686	A1		10/2009
JP	63-191823			8/1988
WO	WO0121373			3/2001
WO	WO0238276			5/2002
WO	WO2008017843			2/2008
WO	2010133531	A1		11/2010
WO	WO2010133531	A1		11/2010
WO	2011/095361			8/2011

OTHER PUBLICATIONS

MRS extrusion technology offers new options in PET, Mar. 1, 2009, pp. 24-26, vol. 11, No. 2, Plastic Additives and Compounding, Elsevier Science, Oxford, Great Britain.

Extended European Search Report from corresponding European Application No. EP15158377 dated Aug. 18, 2015.

Examination Report from corresponding Australian Application No. 2014215998 dated Aug. 26, 2015.

Hannemann, Innovative Aufbereitungslösung für PET mit uneingeschrankter FDA—Lebensmittelzulassung, Presentation, Mar. 15, 2012, 37 pages total, Gneuss Kunststofftechnik GmbH, Germany.

Notice of Opposition from corresponding European Application No. EP13728264 dated Dec. 7, 2015.

International Preliminary Report on Patentability, dated Dec. 11, 2014, from corresponding International Application No. PCT/2013/040753.

"MRS extrusion technology offers new options in PET", Plastics Additives and Compounding, Elsevier Science, Oxford, GB, vol. 11, No. 2, Mar. 1, 2009 (Mar. 1, 2009), pp. 24-26, XP026067788, ISSN: 1464-391X, DOI: 10.1016/S1464-391X(09)70050-9 [retrieved on Mar. 1, 2009].

Gneuss M: "Multi Rotation System Extruder Leads to Breakthrough in Polymer Evacuation", International Fiber Journal, International Media Group, Charlotte, NC, US, vol. 23, No. 1, Feb. 1, 2008 (Feb. 1, 2008), pp. 40-41, XP001514827, ISSN: 1049-801X.

Non-Final Office Action, dated May 26, 2016, from U.S. Appl. No. 14/546,819.

International Search Report from PCT Application No. PCT/US2015/061145 dated Feb. 2, 2016.

Written Opinion from PCT Application No. PCT/US2015/061145 dated Feb. 2, 2016.

International Search Report from PCT Application No. PCT/US2015/061116 dated Feb. 2, 2016.

Written Opinion from PCT Application No. PCT/US2015/061116 dated Feb. 2, 2016.

(56) **References Cited**

OTHER PUBLICATIONS

International Search Report from PCT Application No. PCT/US2015/061174 dated Feb. 5, 2016.
Written Opinion from PCT Application No. PCT/US2015/061174 dated Feb. 5, 2016.
International Search Report from PCT Application No. PCT/US2015/061288 dated Jan. 20, 2016.
Written Opinion from PCT Application No. PCT/US2015/061288 dated Jan. 20, 2016.
Non Final Office Action from U.S. Appl. No. 14/256,261 dated Aug. 21, 2015.
Final Office Action from U.S. Appl. No. 14/256,261 dated Dec. 24, 2015.
Non-Final Office Action from corresponding U.S. Appl. No. 13/892,740 dated Jun. 30, 2016.
Non-Final Office Action from corresponding U.S. Appl. No. 14/546,837 dated Jun. 1, 2016.
Non-Final Office from corresponding U.S. Appl. No. 14/546,847 dated Jun. 13, 2016.
Non-Final Office Action from corresponding U.S. Appl. No. 14/546,796 dated Jun. 22, 2016. 24 pgs.
Final Office Action from corresponding U.S. Appl. No. 14/546,819 dated Oct. 19, 2016.
Final Office Action from corresponding U.S. Appl. No. 14/546,837 dated Oct. 19, 2016.
Final Office from corresponding U.S. Appl. No. 14/546,847 dated Oct. 19, 2016.
Final Office Action from corresponding U.S. Appl. No. 14/546,796 dated Oct. 20, 2016.
"Processing Technology: Processing of Polymer Melts," Oct. 31, 2007, Gneuss Kunststofftechnik GmbH, Dusseldorf, Germany.†

* cited by examiner
† cited by third party

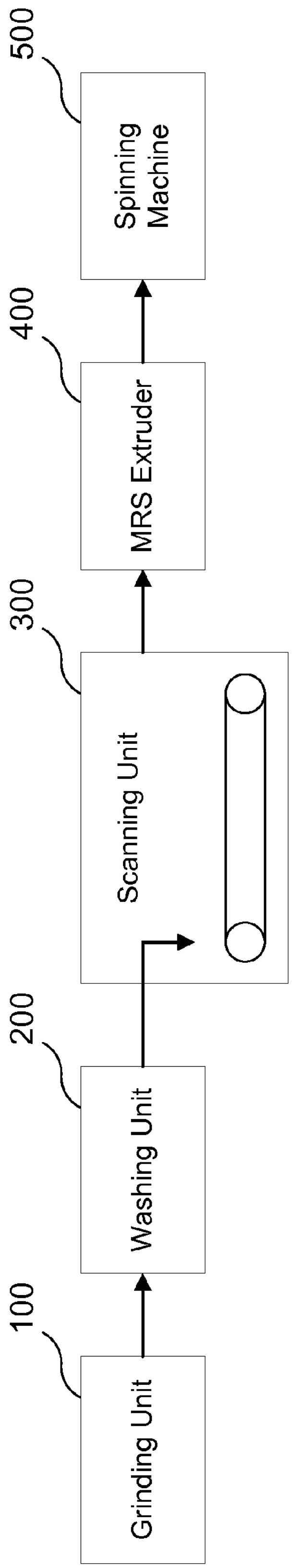
500
Spinning Machine
400
MRS Extruder
300
Scanning Unit
200
Washing Unit
100
Grinding Unit

FIG. 1

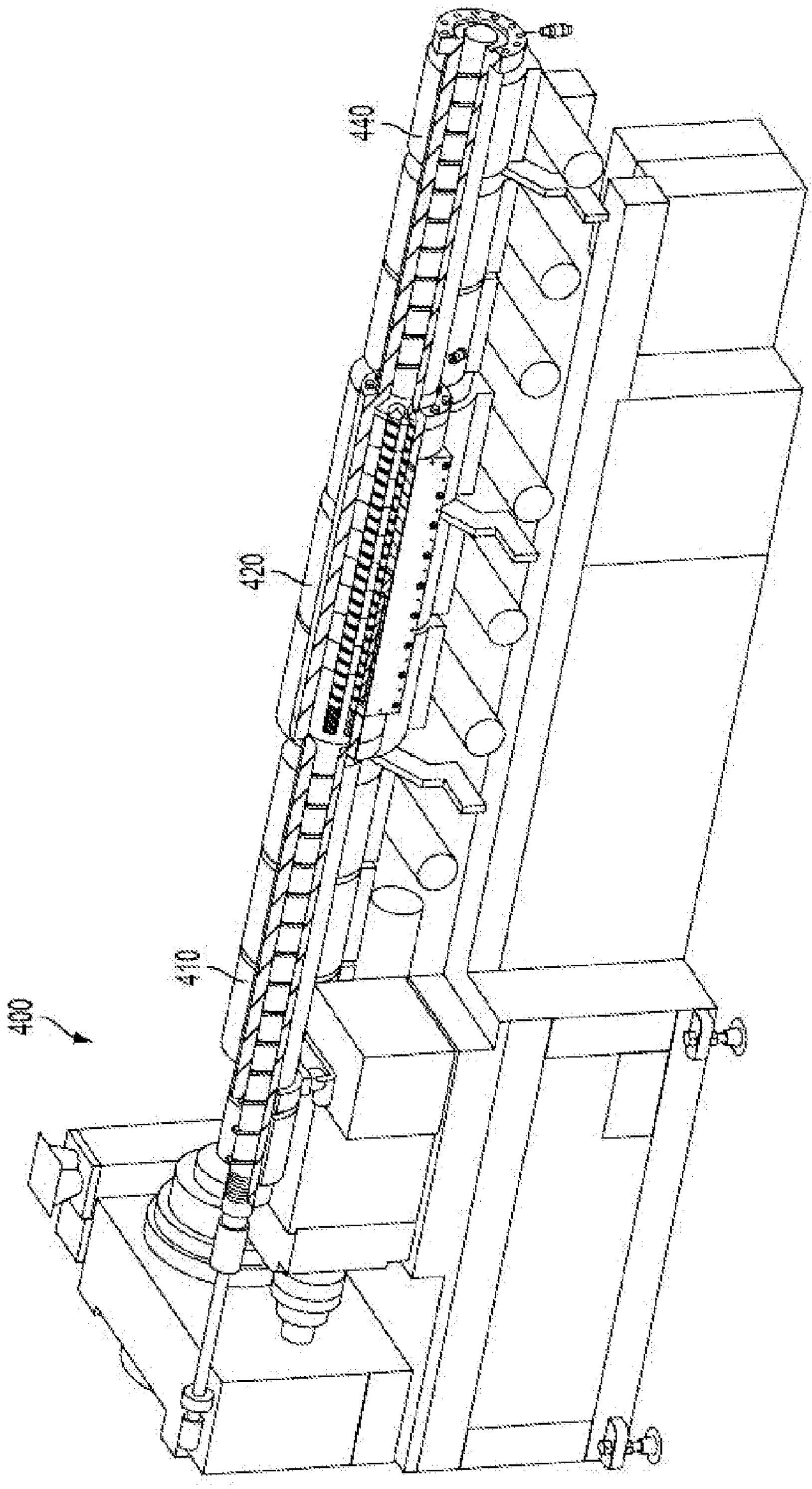

FIG. 2

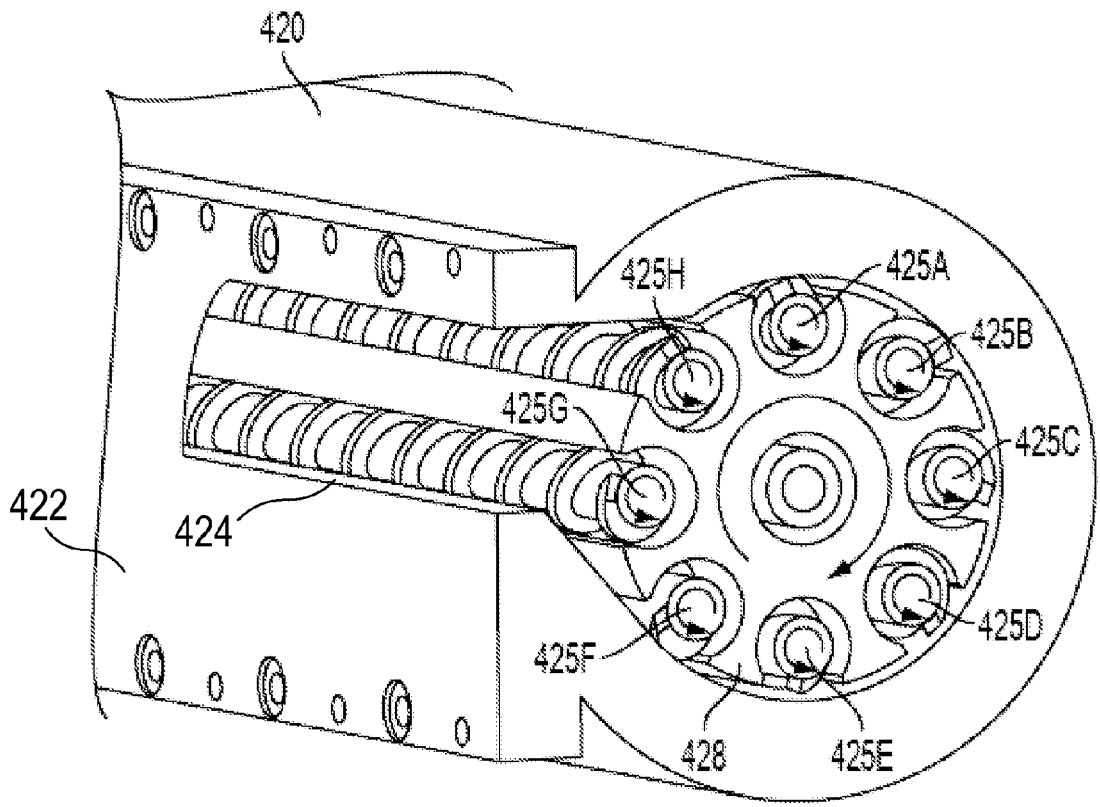

FIG. 3

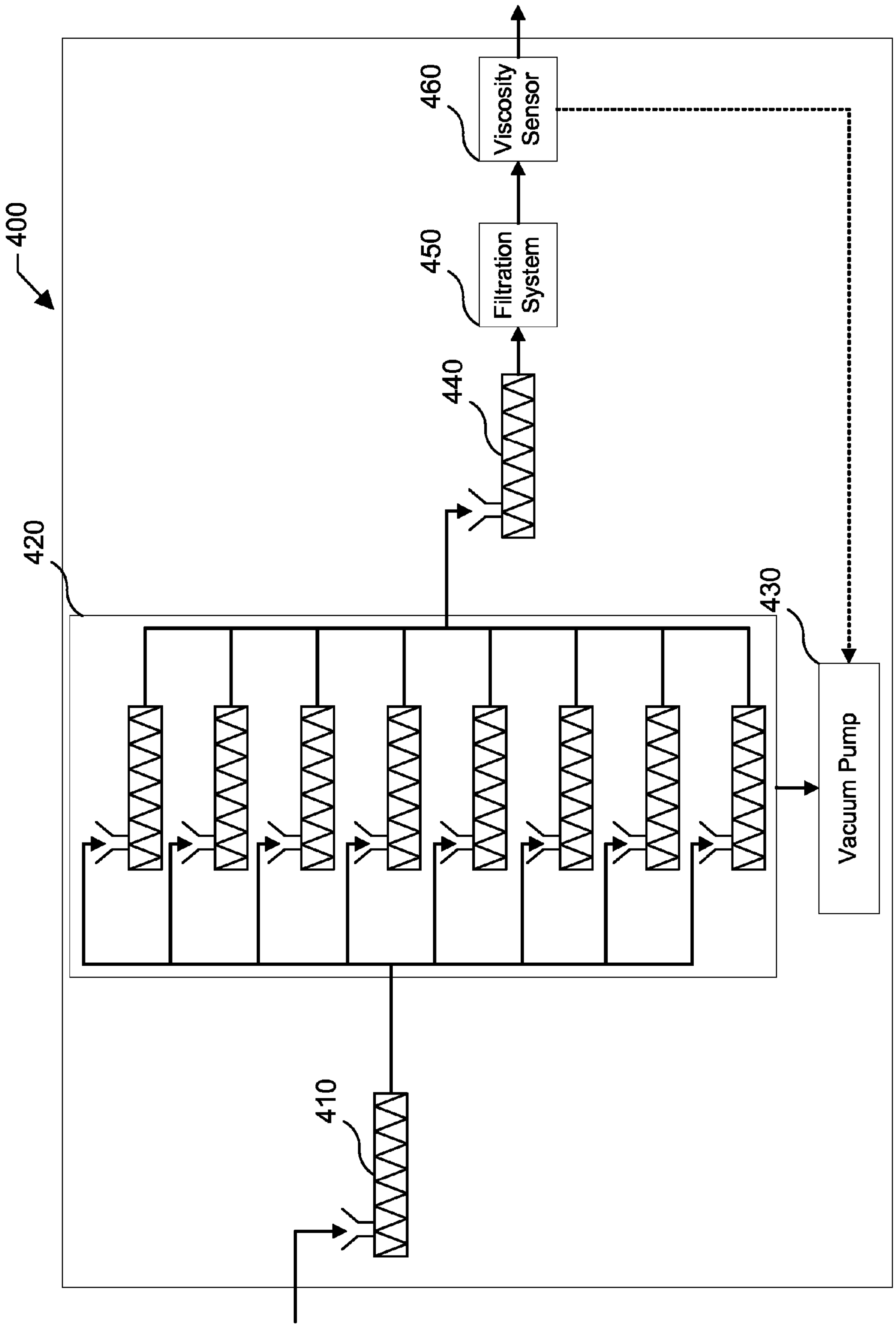
400
410
420
430
440
450
460
Filtration System
Viscosity Sensor
Vacuum Pump

FIG. 4

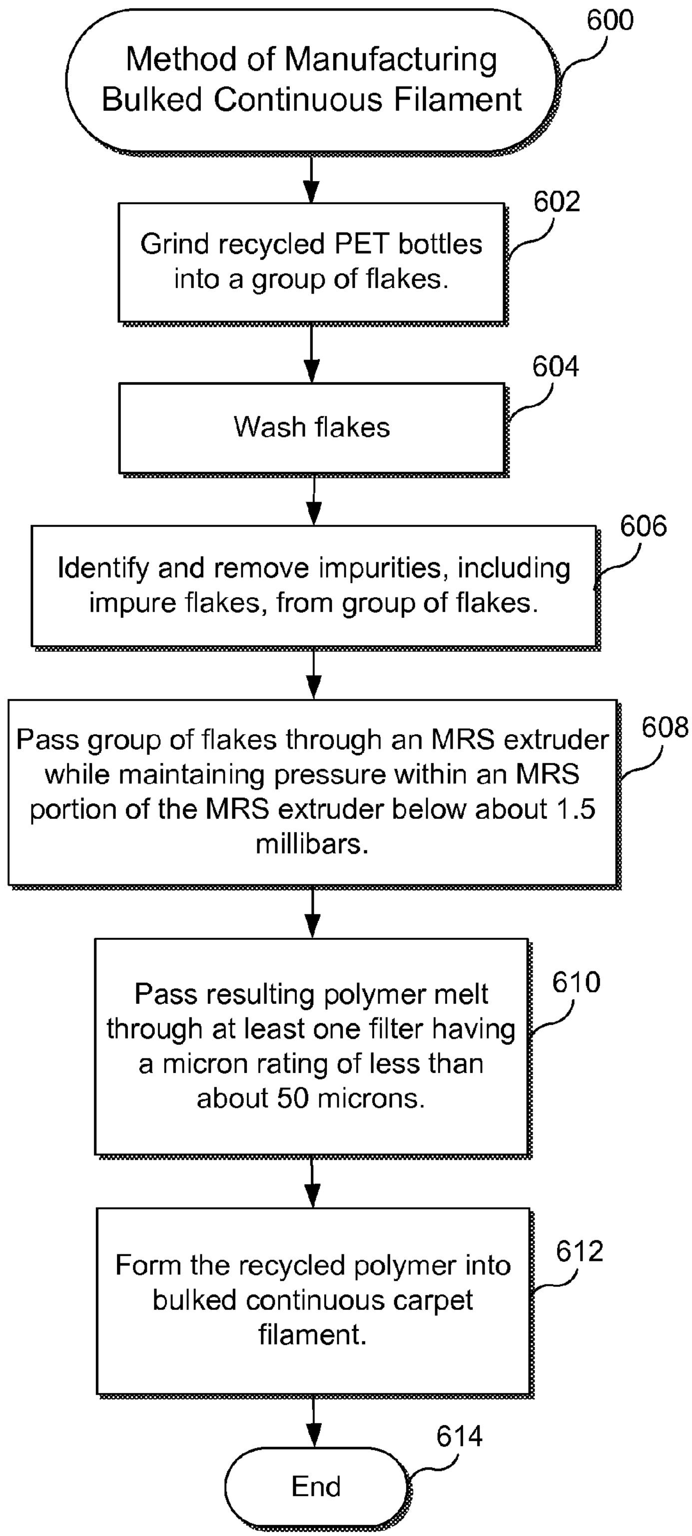
600
Method of Manufacturing Bulked Continuous Filament
602
Grind recycled PET bottles into a group of flakes.
604
Wash flakes
606
Identify and remove impurities, including impure flakes, from group of flakes.
608
Pass group of flakes through an MRS extruder while maintaining pressure within an MRS portion of the MRS extruder below about 1.5 millibars.
610
Pass resulting polymer melt through at least one filter having a micron rating of less than about 50 microns.
612
Form the recycled polymer into bulked continuous carpet filament.
614
End

FIG. 5

SYSTEMS AND METHODS FOR MANUFACTURING BULKED CONTINUOUS FILAMENT

CROSS REFERENCE TO RELATED APPLICATION

This application is a divisional application of U.S. application Ser. No. 13/721,955, entitled "Systems and Methods for Manufacturing Bulked Continuous Filament", filed Dec. 20, 2012, which claimed priority from U.S. Provisional Patent Application No. 61/654,016, filed May 31, 2012, entitled "Systems and Methods for Manufacturing Bulked Continuous Fiber," which are hereby incorporated herein by reference in their entirety.

BACKGROUND

Because pure virgin PET polymer is more expensive than recycled PET polymer, and because of the environmental benefits associated with using recycled polymer, it would be desirable to be able to produce bulked continuous carpet filament from 100% recycled PET polymer (e.g., PET polymer from post-consumer PET bottles).

SUMMARY

A method of manufacturing bulked continuous carpet filament, according to particular embodiments comprises: (A) providing a multi-screw extruder; (B) using a pressure regulation system to reduce a pressure within the multi-screw extruder to below about 1.8 millibars; (C) while maintaining the pressure within the multi-screw extruder below about 1.8 millibars, passing a melt comprising recycled polymer through the multi-screw extruder; and (D) after the step of passing the melt of recycled polymer through the multi-screw extruder, forming the recycled polymer into bulked continuous carpet filament. In various embodiments, the multi-screw extruder comprises: (i) a first satellite screw extruder comprising a first satellite screw that is mounted to rotate about a central axis of the first satellite screw; (ii) a second satellite screw extruder comprising a second satellite screw that is mounted to rotate about a central axis of the second satellite screw; and (iii) the pressure regulation system that is adapted to maintain a pressure within the first and second satellite screw extruders below about 1.8 millibars. In particular embodiments, when passing the melt comprising recycled polymer through the multi-screw extruder: (1) a first portion of the melt passes through the first satellite screw extruder; and (2) a second portion of the melt passes through the second satellite screw extruder.

An extruder for use in extruding a polymer melt, according to particular embodiments, comprises: (1) a first satellite screw extruder comprising a first satellite screw that is mounted to rotate about a central axis of the first satellite screw; (2) a second satellite screw extruder comprising a second satellite screw that is mounted to rotate about a central axis of the second satellite screw; and (3) a pressure regulation system that is adapted to maintain a pressure within the first and second satellite screw extruders below a pressure of about 1.5 millibars as the polymer melt passes through the first and second screw extruders.

A bulked continuous carpet filament, according to various embodiments, consists essentially of a recycled polymer.

A method of manufacturing carpet filament, according to particular embodiments, comprises the steps of: (A) washing a group of polymer flakes to remove at least a portion of one or more contaminants from a surface of the flakes, the group of flakes comprising a first plurality of flakes that consist essentially of PET and a second plurality of flakes that do not consist essentially of PET; (B) after the step of washing the first plurality of flakes: (i) scanning the washed group of flakes to identify the second plurality of flakes, and (ii) separating the second plurality of flakes from the first plurality of flakes; (C) melting the second plurality of flakes to produce a polymer melt; (D) providing an extruder that extrudes material in a plurality of different extrusion streams; (E) reducing a pressure within the extruder to below about 1.5 millibars; (F) while maintaining the pressure within the extruder below about 1.5 millibars, passing the polymer melt through the extruder so that the polymer melt is divided into a plurality of extrusion streams, each having a pressure below about 1.5 millibars; (G) after passing the polymer melt through the extruder, filtering the polymer melt through at least one filter; and (H) after passing the polymer melt through the filter, forming the recycled polymer into bulked continuous carpet filament.

BRIEF DESCRIPTION OF THE DRAWINGS

Having described various embodiments in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. **1** depicts a process flow, according to a particular embodiment, for manufacturing bulked continuous carpet filament.

FIG. **2** is a perspective view of an MRS extruder that is suitable for use in the process of FIG. **1**.

FIG. **3** is a cross-sectional view of an exemplary MRS section of the MRS extruder of FIG. **2**.

FIG. **4** depicts a process flow depicting the flow of polymer through an MRS extruder and filtration system according to a particular embodiment.

FIG. **5** is a high-level flow chart of a method, according to various embodiments, of manufacturing bulked continuous carpet filament.

DETAILED DESCRIPTION OF VARIOUS EMBODIMENTS

Various embodiments will now be described in greater detail. It should be understood that the invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

I. Overview

New processes for making fiber from recycled polymer (e.g., recycled PET polymer) are described below. In various embodiments, this new process: (1) is more effective than earlier processes in removing contaminates and water from the recycled polymer; and/or (2) does not require the polymer to be melted and cooled as many times as in earlier processes. In at least one embodiment, the improved process results in a recycled PET polymer having a polymer quality that is high enough that the PET polymer may be used in producing bulked continuous carpet filament from 100% recycled PET content (e.g., 100% from PET obtained from previously used PET bottles). In particular embodiments, the recycled PET polymer has an intrinsic viscosity of at least about 0.79 dL/g (e.g., of between about 0.79 dL/g and about 1.00 dL/g).

II. More Detailed Discussion

A BCF (bulked continuous filament) manufacturing process, according to a particular embodiment, may generally be broken down into three steps: (1) preparing flakes of PET polymer from post-consumer bottles for use in the process; (2) passing the flakes through an extruder that melts the flakes and purifies the resulting PET polymer; and (3) feeding the purified polymer into a spinning machine that turns the polymer into filament for use in manufacturing carpets. These three steps are described in greater detail below.

Step 1: Preparing Flakes of PET Polymer from Post-Consumer Bottles

In a particular embodiment, the step of preparing flakes of PET polymer from post-consumer bottles comprises: (A) sorting post-consumer PET bottles and grinding the bottles into flakes; (B) washing the flakes; and (C) identifying and removing any impurities or impure flakes.

A. Sorting Post-Consumer PET Bottles and Grinding the Bottles into Flakes

In particular embodiments, bales of clear and mixed colored recycled post-consumer (e.g., "curbside") PET bottles (or other containers) obtained from various recycling facilities make-up the post-consumer PET containers for use in the process. In other embodiments, the source of the post-consumer PET containers may be returned 'deposit' bottles (e.g., PET bottles whose price includes a deposit that is returned to a customer when the customer returns the bottle after consuming the bottle's contents). The curbside or returned "post-consumer" or "recycled" containers may contain a small level of non-PET contaminates. The contaminants in the containers may include, for example, non-PET polymeric contaminants (e.g., PVC, PLA, PP, PE, PS, PA, etc.), metal (e.g., ferrous and non-ferrous metal), paper, cardboard, sand, glass or other unwanted materials that may find their way into the collection of recycled PET. The non-PET contaminants may be removed from the desired PET components, for example, through one or more of the various processes described below.

In particular embodiments, smaller components and debris (e.g., components and debris greater than 2 inches in size) are removed from the whole bottles via a rotating trammel. Various metal removal magnets and eddy current systems may be incorporated into the process to remove any metal contaminants. Near Infra-Red optical sorting equipment such as the NRT Multi Sort IR machine from Bulk Handling Systems Company of Eugene, Oreg., or the Spyder IR machine from National Recovery Technologies of Nashville, Tenn., may be utilized to remove any loose polymeric contaminants that may be mixed in with the PET flakes (e.g., PVC, PLA, PP, PE, PS, and PA). Additionally, automated X-ray sorting equipment such as a VINYLCYCLE machine from National Recovery Technologies of Nashville, Tenn. may be utilized to remove remaining PVC contaminants.

In particular embodiments, a binary segregation of the clear materials from the colored materials is achieved using automated color sorting equipment equipped with a camera detection system (e.g., an Multisort ES machine from National Recovery Technologies of Nashville, Tenn.). In various embodiments, manual sorters are stationed at various points on the line to remove contaminants not removed by the sorter and any colored bottles. In particular embodiments, the sorted material is taken through a granulation step (e.g., using a 50B Granulator machine from Cumberland Engineering Corporation of New Berlin, Wis.) to size reduce (e.g., grind) the bottles down to a size of less than one half of an inch. In various embodiments, the bottle labels are removed from the resultant "dirty flake" (e.g., the PET flakes formed during the granulation step) via an air separation system prior to entering the wash process.

B. Washing the Flakes

In particular embodiments, the "dirty flake" is then mixed into a series of wash tanks. As part of the wash process, in various embodiments, an aqueous density separation is utilized to separate the olefin bottle caps (which may, for example, be present in the "dirty flake" as remnants from recycled PET bottles) from the higher specific gravity PET flakes. In particular embodiments, the flakes are washed in a heated caustic bath to about 190 degrees Fahrenheit. In particular embodiments, the caustic bath is maintained at a concentration of between about 0.6% and about 1.2% sodium hydroxide. In various embodiments, soap surfactants as well as defoaming agents are added to the caustic bath, for example, to further increase the separation and cleaning of the flakes. A double rinse system then washes the caustic from the flakes.

In various embodiments, the flake is centrifugally dewatered and then dried with hot air to at least substantially remove any surface moisture. The resultant "clean flake" is then processed through an electrostatic separation system (e.g., an electrostatic separator from Carpco, Inc. of Jacksonville, Fla.) and a flake metal detection system (e.g., an MSS Metal Sorting System) to further remove any metal contaminants that remain in the flake. In particular embodiments, an air separation step removes any remaining label from the clean flake. In various embodiments, the flake is then taken through a flake color sorting step (e.g., using an OPTIMIX machine from TSM Control Systems of Dundalk, Ireland) to remove any remaining color contaminants remaining in the flake. In various embodiments, an electro-optical flake sorter based at least in part on Raman technology (e.g., a Powersort 200 from Unisensor Sensorsysteme GmbH of Karlsruhe, Germany) performs the final polymer separation to remove any non-PET polymers remaining in the flake. This step may also further remove any remaining metal contaminants and color contaminants.

In various embodiments, the combination of these steps delivers substantially clean (e.g., clean) PET bottle flake comprising less than about 50 parts per million PVC (e.g., 25 ppm PVC) and less than about 15 parts per million metals for use in the downstream extrusion process described below.

C. Identifying and Removing Impurities and Impure Flakes

In particular embodiments, after the flakes are washed, they are fed down a conveyor and scanned with a high-speed laser system **300**. In various embodiments, particular lasers that make up the high-speed laser system **300** are configured to detect the presence of particular contaminates (e.g., PVC or Aluminum). Flakes that are identified as not consisting essentially of PET may be blown from the main stream of flakes with air jets. In various embodiments, the resulting level of non-PET flakes is less than 25 ppm.

In various embodiments, the system is adapted to ensure that the PET polymer being processed into filament is substantially free of water (e.g., entirely free of water). In a particular embodiment, the flakes are placed into a pre-conditioner for between about 20 and about 40 minutes (e.g., about 30 minutes) during which the pre-conditioner blows the surface water off of the flakes. In particular embodiments, interstitial water remains within the flakes. In various embodiments, these "wet" flakes (e.g., flakes comprising interstitial water) may then be fed into an extruder (e.g., as described in Step 2 below), which includes a vacuum setup designed to remove—among other things—the interstitial water that remains present in the flakes following the quick-drying process described above.

Step 2: Using an Extrusion System to Melt and Purify PET Flakes

In particular embodiments, an extruder is used to turn the wet flakes described above into a molten recycled PET polymer and to perform a number of purification processes to prepare the polymer to be turned into BCF for carpet. As noted above, in various embodiments, after STEP **1** is complete, the recycled PET polymer flakes are wet (e.g., surface water is substantially removed (e.g., fully removed) from the flakes, but interstitial water remains in the flakes). In particular embodiments, these wet flakes are fed into a Multiple Rotating Screw ("MRS") extruder **400**. In other embodiments, the wet flakes are fed into any other suitable extruder (e.g., a twin screw extruder, a multiple screw extruder, a planetary extruder, or any other suitable extrusion system). An exemplary MRS Extruder **400** is shown in FIGS. **2** and **3**. A particular example of such an MRS extruder is described in U.S. Published Patent Application 2005/0047267, entitled "Extruder for Producing Molten Plastic Materials", which was published on Mar. 3, 2005, and which is hereby incorporated herein by reference.

As may be understood from this figure, in particular embodiments, the MRS extruder includes a first single-screw extruder section **410** for feeding material into an MRS section **420** and a second single-screw extruder section **440** for transporting material away from the MRS section.

In various embodiments, the wet flakes are fed directly into the MRS extruder **400** substantially immediately (e.g., immediately) following the washing step described above (e.g., without drying the flakes or allowing the flakes to dry). In particular embodiments, a system that feeds the wet flakes directly into the MRS Extruder **400** substantially immediately (e.g., immediately) following the washing step described above may consume about 20% less energy than a system that substantially fully pre-dries the flakes before extrusion (e.g., a system that pre-dries the flakes by passing hot air over the wet flakes for a prolonged period of time). In various embodiments, a system that feeds the wet flakes directly into the MRS Extruder **400** substantially immediately (e.g., immediately) following the washing step described above avoids the need to wait a period of time (e.g., up to eight hours) generally required to fully dry the flakes (e.g., remove all of the surface and interstitial water from the flakes).

FIG. **4** depicts a process flow that illustrates the various processes performed by the MRS Extruder **400** in a particular embodiment. In the embodiment shown in this figure, the wet flakes are first fed through the MRS extruder's first single-screw extruder section **410**, which may, for example, generate sufficient heat (e.g., via shearing) to at least substantially melt (e.g., melt) the wet flakes.

The resultant polymer melt (e.g., comprising the melted flakes), in various embodiments, is then fed into the extruder's MRS section **420**, in which the extruder separates the melt flow into a plurality of different streams (e.g., 4, 6, 8, or more streams) through a plurality of open chambers. FIG. **3** shows a detailed cutaway view of an MRS Section **420** according to a particular embodiment. In particular embodiments, such as the embodiment shown in this figure, the MRS Section **420** separates the melt flow into eight different streams, which are subsequently fed through eight satellite screws **425**A-H. As may be understood from FIG. **2**, in particular embodiments, these satellite screws are substantially parallel (e.g., parallel) to one other and to a primary screw axis of the MRS Machine **400**.

In the MRS section **420**, in various embodiments, the satellite screws **425**A-H may, for example, rotate faster than (e.g., about four times faster than) in previous systems. As shown in FIG. **3**, in particular embodiments: (1) the satellite screws **425**A-H are arranged within a single screw drum **428** that is mounted to rotate about its central axis; and (2) the satellite screws **425**A-H are configured to rotate in a direction that is opposite to the direction in which the single screw drum rotates **428**. In various other embodiments, the satellite screws **425**A-H and the single screw drum **428** rotate in the same direction. In particular embodiments, the rotation of the satellite screws **425**A-H is driven by a ring gear. Also, in various embodiments, the single screw drum **428** rotates about four times faster than each individual satellite screw **425**A-H. In certain embodiments, the satellite screws **425**A-H rotate at substantially similar (e.g., the same) speeds.

In various embodiments, as may be understood from FIG. **4**, the satellite screws **425**A-H are housed within respective extruder barrels, which may, for example be about 30% open to the outer chamber of the MRS section **420**. In particular embodiments, the rotation of the satellite screws **425**A-H and single screw drum **428** increases the surface exchange of the polymer melt (e.g., exposes more surface area of the melted polymer to the open chamber than in previous systems). In various embodiments, the MRS section **420** creates a melt surface area that is, for example, between about twenty and about thirty times greater than the melt surface area created by a co-rotating twin screw extruder. In a particular embodiment, the MRS section **420** creates a melt surface area that is, for example, about twenty five times greater than the melt surface area created by a co-rotating twin screw extruder

In various embodiments, the MRS extruder's MRS Section **420** is fitted with a Vacuum Pump **430** that is attached to a vacuum attachment portion **422** of the MRS section **420** so that the Vacuum Pump **430** is in communication with the interior of the MRS section via a suitable opening **424** in the MRS section's housing. In still other embodiments, the MRS Section **420** is fitted with a series of Vacuum Pumps. In particular embodiments, the Vacuum Pump **430** is configured to reduce the pressure within the interior of the MRS Section **420** to a pressure that is between about 0.5 millibars and about 5 millibars. In particular embodiments, the Vacuum Pump **430** is configured to reduce the pressure in the MRS Section **420** to less than about 1.5 millibars (e.g., about 1 millibar or less). The low-pressure vacuum created by the Vacuum Pump **430** in the MRS Section **420** may remove, for example: (1) volatile organics present in the melted polymer as the melted polymer passes through the MRS Section **420**; and/or (2) at least a portion of any interstitial water that was present in the wet flakes when the wet flakes entered the MRS Extruder **400**. In various embodiments, the low-pressure vacuum removes substantially all (e.g., all) of the water and contaminants from the polymer stream.

In a particular example, the Vacuum Pump **430** comprises three mechanical lobe vacuum pumps (e.g., arranged in series) to reduce the pressure in the chamber to a suitable level (e.g., to a pressure of about 1.0 millibar). In other embodiments, rather than the three mechanical lobe vacuum pump arrangement discussed above, the Vacuum Pump **430** includes a jet vacuum pump fit to the MRS extruder. In various embodiments, the jet vacuum pump is configured to achieve about 1 millibar of pressure in the interior of the MRS section **420** and about the same results described above regarding a resulting intrinsic viscosity of the polymer melt. In various embodiments, using a jet vacuum pump can be advantageous because jet vacuum pumps are steam powered and therefore substantially self-cleaning (e.g., self-cleaning), thereby reducing the maintenance required in comparison to mechanical lobe pumps (which may, for example, require repeated cleaning due to volatiles coming off and condensing on the lobes of the pump). In a particular embodiment, the Vacuum Pump **430** is a jet vacuum pump is made by Arpuma GmbH of Bergheim, Germany.

In particular embodiments, after the molten polymer is run the through the multi-stream MRS Section **420**, the streams of molten polymer are recombined and flow into the MRS extruder's second single screw section **440**. In various embodiments, the single stream of molten polymer is next run through a filtration system **450** that includes at least one filter. In a particular embodiment, the filtration system **450** includes two levels of filtration (e.g., a 40 micron screen filter followed by a 25 micron screen filter). Although, in various embodiments, water and volatile organic impurities are removed during the vacuum process as discussed above, particulate contaminates such as, for example, aluminum particles, sand, dirt, and other contaminants may remain in the polymer melt. Thus, this filtration step may be advantageous in removing particulate contaminates (e.g., particulate contaminates that were not removed in the MRS Section **420**).

In particular embodiments, a viscosity sensor **460** (see FIG. **4**) is used to sense the melt viscosity of the molten polymer stream following its passage through the filtration system **450**. In various embodiments, the viscosity sensor **460**, measures the melt viscosity of the stream, for example, by measuring the stream's pressure drop across a known area. In particular embodiments, in response to measuring an intrinsic viscosity of the stream that is below a predetermined level (e.g., below about 0.8 g/dL), the system may: (1) discard the portion of the stream with low intrinsic viscosity; and/or (2) lower the pressure in the MRS Section **420** in order to achieve a higher intrinsic viscosity in the polymer melt. In particular embodiments, decreasing the pressure in the MRS Section **420** is executed in a substantially automated manner (e.g., automatically) using the viscosity sensor in a computer-controlled feedback control loop with the vacuum section **430**.

In particular embodiments, removing the water and contaminates from the polymer improves the intrinsic viscosity of the recycled PET polymer by allowing polymer chains in the polymer to reconnect and extend the chain length. In particular embodiments, following its passage through the MRS Section **420** with its attached Vacuum Pump **430**, the recycled polymer melt has an intrinsic viscosity of at least about 0.79 dL/g (e.g., of between about 0.79 dL/g and about 1.00 dL/g). In particular embodiments, passage through the low pressure MRS Section **420** purifies the recycled polymer melt (e.g., by removing the contaminants and interstitial water) and makes the recycled polymer substantially structurally similar to (e.g., structurally the same as) pure virgin PET polymer. In particular embodiments, the water removed by the vacuum includes both water from the wash water used to clean the recycled PET bottles as described above, as well as from unreacted water generated by the melting of the PET polymer in the single screw heater **410** (e.g., interstitial water). In particular embodiments, the majority of water present in the polymer is wash water, but some percentage may be unreacted water.

In particular embodiments, the resulting polymer is a recycled PET polymer (e.g., obtained 100% from post-consumer PET products, such as PET bottles or containers) having a polymer quality that is suitable for use in producing PET carpet filament using substantially only (e.g., only) PET from recycled PET products.

Step 3: Purified PET Polymer Fed into Spinning Machine to be Turned into Carpet Yarn

In particular embodiments, after the recycled PET polymer has been extruded and purified by the above-described extrusion process, the resulting molten recycled PET polymer is fed directly into a BCF (or "spinning") machine **500** that is configured to turn the molten polymer into bulked continuous filament. For example, in various embodiments, the output of the MRS extruder **400** is connected substantially directly (e.g., directly) to the input of the spinning machine **500** so that molten polymer from the extruder is fed directly into the spinning machine **500**. This process may be advantageous because molten polymer may, in certain embodiments, not need to be cooled into pellets after extrusion (as it would need to be if the recycled polymer were being mixed with virgin PET polymer). In particular embodiments, not cooling the recycled molten polymer into pellets serves to avoid potential chain scission in the polymer that might lower the polymer's intrinsic viscosity.

In particular embodiments, the spinning machine **500** extrudes molten polymer through small holes in a spinneret in order to produce carpet yarn filament from the polymer. In particular embodiments, the molten recycled PET polymer cools after leaving the spinneret. The carpet yarn is then taken up by rollers and ultimately turned into filaments that are used to produce carpet. In various embodiments, the carpet yarn produced by the spinning machine **500** may have a tenacity between about 3 gram-force per unit denier (gf/den) and about 9 gf/den. In particular embodiments, the resulting carpet yarn has a tenacity of at least about 3 gf/den.

In particular embodiments, the spinning machine **500** used in the process described above is the Sytec One spinning machine manufactured by Oerlika Neumag of Neumuenster, Germany. The Sytec One machine may be especially adapted for hard-to-run fibers, such as nylon or solution-dyed fibers, where the filaments are prone to breakage during processing. In various embodiments, the Sytec One machine keeps the runs downstream of the spinneret as straight as possible, uses only one threadline, and is designed to be quick to rethread when there are filament breaks.

Although the example described above describes using the Sytec One spinning machine to produce carpet yarn filament from the polymer, it should be understood that any other suitable spinning machine may be used. Such spinning machines may include, for example, any suitable one-threadline or three-threadline spinning machine made by Oerlika Neumag of Neumuenster, Germany or any other company.

In various embodiments, the improved strength of the recycled PET polymer generated using the process above allows it to be run at higher speeds through the spinning machine **500** than would be possible using pure virgin PET polymer. This may allow for higher processing speeds than are possible when using virgin PET polymer.

Summary of Exemplary Process

FIG. **5** provides a high-level summary of the method of manufacturing bulked continuous filament described above.

As shown in the figure, the method begins at Step **602**, where recycled PET bottles are ground into a group of flakes. Next, at Step **604**, the group of flakes is washed to remove contaminants from the flakes' respective outer surfaces. Next, at Step **606**, the group of flakes is scanned (e.g., using one or more of the methods discussed above) to identify impurities, including impure flakes. These impurities, and impure flakes, are then removed from the group of flakes.

Next, at Step **608**, the group of flakes is passed through an MRS extruder while maintaining the pressure within an MRS portion of the extruder below about 1.5 millibars. At Step **610**, the resulting polymer melt is passed through at least one filter having a micron rating of less than about 50 microns. Finally, at Step **612**, the recycled polymer is formed into bulked continuous carpet filament, which may be used in producing carpet. The method then ends at Step **614**.

Alternative Embodiments

In particular embodiments, the system may comprise alternative components or perform alternative processes in order to produce substantially continuous BCF from 100% recycled PET, or other recycled polymer. Exemplary alternatives are discussed below.

Non-MRS Extrusion System

In particular embodiments, the process may utilize a polymer flow extrusion system other than the MRS Extruder described above. The alternative extrusion system may include for example, a twin screw extruder, a multiple screw extruder, a planetary extruder, or any other suitable extrusion system. In a particular embodiment, the process may include a plurality of any combination of any suitable conical screw extruders (e.g., four twin screw extruders, three multiple screw extruders, etc.).

Making Carpet Yarn from 100% Recycled Carpet

In particular embodiments, the process described above may be adapted for processing and preparing old carpet (or any other suitable post-consumer product) to produce new carpet yarn comprising 100% recycled carpet. In such embodiments, the process would begin by grinding and washing recycled carpet rather than recycled PET bottles. In various embodiments where old carpet is converted into new carpet yarn comprising 100% recycled carpet, the process may comprise additional steps to remove additional materials or impurities that may be present in recycled carpet that may not be present in recycled PET bottles (e.g., carpet backing, adhesive, etc.).

Other Sources of Recycled PET

In various embodiments, the process described above is adapted for processing recycled PET from any suitable source (e.g., sources other than recycled bottles or carpet) to produce new carpet yarn comprising 100% recycled PET.

CONCLUSION

Many modifications and other embodiments of the invention will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. For example, although the vacuum system discussed above is described as being configured to maintain the pressure in the open chambers of the MRS extruder to about 1 mbar, in other embodiments, the vacuum system may be adapted to maintain the pressure in the open chambers of the MRS extruder at pressures greater than, or less

than, 1 mbar. For example, the vacuum system may be adapted to maintain this pressure at between about 0.5 mbar and about 1.2 mbar.

Similarly, although various embodiments of the systems described above may be adapted to produce carpet filament from substantially only recycled PET (so the resulting carpet filament would comprise, consist of, and/or consist essentially of recycled PET), in other embodiments, the system may be adapted to produce carpet filament from a combination of recycled PET and virgin PET. The resulting carpet filament may, for example, comprise, consist of, and/or consist essentially of between about 80% and about 100% recycled PET, and between about 0% and about 20% virgin PET.

Also, while various embodiments are discussed above in regard to producing carpet filament from PET, similar techniques may be used to produce carpet filament from other polymers. Similarly, while various embodiments are discussed above in regard to producing carpet filament from PET, similar techniques may be used to produce other products from PET or other polymers.

In addition, it should be understood that various embodiments may omit any of the steps described above or add additional steps.

In light of the above, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for the purposes of limitation.

I claim:

1. A multi-screw extruder for use in extruding a polymer melt, said extruder comprising:

a first satellite screw extruder, said first satellite screw extruder comprising a first satellite screw that is mounted to rotate about a central axis of said first satellite screw;

a second satellite screw extruder, said second satellite screw extruder comprising a second satellite screw that is mounted to rotate about a central axis of said second satellite screw;

a pressure regulation system that is adapted to maintain a pressure within said first and second satellite screw extruders below a pressure of about 1.5 millibars as said polymer melt passes through said first and second screw extruders; and

a controller that operates said pressure regulation system to maintain said pressure within said first and second satellite screw extruders below said pressure of about 1.5 millibars while said multi-screw extruder is extruding said polymer melt.

2. The multi-screw extruder of claim **1**, wherein:

said pressure regulation system is adapted to maintain a pressure within said first and second satellite screw extruders below a pressure of about 1 millibar as said polymer melt passes through said first and second screw extruders; and

said controller operates said pressure regulation system to maintain said pressure within said first and second satellite screw extruders below said pressure of about 1 millibar while said multi-screw extruder is extruding said polymer melt.

3. The multi-screw extruder of claim **2**, wherein:

said extruder comprises a third satellite screw extruder, said third satellite screw extruder comprising a third satellite screw that is mounted to rotate about a central axis of said third satellite screw;

said pressure regulation system is adapted to maintain a pressure within said third satellite screw extruder below a pressure of about 1.5 millibars as said polymer melt passes through said third screw extruder;

said satellite screw extruder support system is adapted to orbitally rotate said third satellite screw about said main axis as said polymer melt passes through said third screw extruder; and

said main axis is substantially parallel to said central axis of said third satellite screw.

4. The multi-screw extruder of claim **3**, wherein:

said extruder comprises a fourth satellite screw extruder, said fourth satellite screw extruder comprising a fourth satellite screw that is mounted to rotate about a central axis of said fourth satellite screw;

said pressure regulation system is adapted to maintain a pressure within said fourth satellite screw extruder below a pressure of about 1.5 millibars as said polymer melt passes through said fourth screw extruder;

said satellite screw extruder support system is adapted to orbitally rotate said fourth satellite screw about said main axis as said polymer melt passes through said fourth screw extruder; and

said main axis is substantially parallel to said central axis of said fourth satellite screw.

5. The multi-screw extruder of claim **1**, wherein said extruder comprises a satellite screw extruder support system that is adapted to orbitally rotate said first and second satellite screws about a main axis as said polymer melt passes through said first and second screw extruders, said main axis being substantially parallel to both: (1) said central axis of said first satellite screw; and (2) said central axis of said second satellite screw.

6. The multi-screw extruder of claim **5**, wherein:

said satellite screw extruder support system comprises a drum that is adapted to rotate about said main axis; said drum defines a first screw barrel having a central axis that is substantially parallel to said main axis;

said drum defines a second screw barrel having a central axis that is substantially parallel to said main axis;

said first satellite screw is rotatably mounted within said first screw barrel; and

said second satellite screw is rotatably mounted within said second screw barrel.

7. The multi-screw extruder of claim **6**, wherein said pressure regulation system is adapted to maintain a pressure within said first and second satellite screw extruders below a pressure of about 1 millibar as said polymer melt passes through said first and second screw extruders; and

said controller operates said pressure regulation system to maintain said pressure within said first and second satellite screw extruders below said pressure of about 1 millibar while said multi-screw extruder is extruding said polymer melt.

8. The multi-screw extruder of claim **7**, wherein said pressure regulation system comprises at least one vacuum pump.

9. The multi-screw extruder of claim **1**, further comprising a viscosity sensor adapted to measure an intrinsic viscosity of said polymer melt after said polymer melt has passed through said first and second screw extruders.

10. The multi-screw extruder of claim **9**, wherein, in response to determining that said measured intrinsic viscosity is below a particular intrinsic viscosity, said controller operates said pressure regulation system to lower said pressure within said first and second satellite screw extruders.

11. The multi-screw extruder of claim **10**, wherein said particular intrinsic viscosity is 0.8 g/dL.

12. A multi-screw extruder for at least partially removing impurities from a polymer melt, wherein said extruder comprises:

at least six satellite screw extruders, each of said at least six satellite screw extruders comprising a satellite screw that is mounted to rotate about a respective central axis of each said satellite screw;

at least one vacuum pump that is adapted to maintain a pressure within said at least six satellite screw extruders below a pressure of about 5 millibars as said polymer melt passes through said at least six satellite screw extruders;

a viscosity sensor that measures a melt viscosity of said polymer melt after said polymer melt has assed through said at least six satellite screw extruders;

a computer-controller that operates said at least one vacuum pump to maintain said pressure within said at least six satellite screw extruders below said pressure of about 5 millibars as said polymer melt passes through said at least six satellite screw extruders and further operates in a feedback control loop with said viscosity sensor to operate said at least one vacuum pump to further reduce said pressure within said at least six satellite screw extruders in response to using said viscosity sensor to measure an intrinsic viscosity of said polymer melt that is below a predetermined level; and

a satellite screw drum that houses said at least six satellite screw extruders orbitally rotates said at least six satellite screw extruders about a main axis as said polymer melt passes through said at least six satellite screw extruders, said main axis being substantially parallel to each said central axis.

13. The multi-screw extruder of claim **12**, wherein said extruder is adapted to separate said polymer melt into at least six different streams and feed said at least six different streams into said at least six satellite screw extruders.

14. The multi-screw extruder of claim **13**, wherein each of said at least six satellite screw extruders is adapted to rotate in a direction that is the same as a direction in which said satellite screw drum is adapted to rotate.

15. The multi-screw extruder of claim **13**, wherein each of said at least six satellite screw extruders is adapted to rotate in a direction that is opposite to a direction in which said satellite screw drum is adapted to rotate.

16. The multi-screw extruder of claim **13**, wherein said multi-screw extruder:

comprises a single screw extruder adjacent said satellite screw drum; and

is adapted to recombine said at least six different streams into a single stream in said single screw extruder.

17. The multi-screw extruder of claim **12**, wherein:

said at least one vacuum pump is configured to maintain a pressure within said at least six satellite screw extruders below a pressure of about 1.5 millibars; and

said computer-controller operates said at least one vacuum pump to maintain said pressure within said at least six satellite screw extruders below said pressure of about 1.5 millibars as said polymer melt passes through said at least six satellite screw extruders.

18. The multi-screw extruder of claim **17**, wherein said at least one vacuum pump comprises a jet vacuum pump.

19. An apparatus for at least partially removing impurities from a recycled polymer comprising:

a first satellite screw extruder that is mounted to rotate about a central axis of said first satellite screw and adapted to at least substantially melt said recycled polymer into molten recycled polymer;

a multi-screw extruder comprising a plurality of satellite screws, each of said plurality of satellite screws being mounted to rotate about a respective central axis, wherein said multi-screw extruder is adapted to orbitally rotate said plurality of satellite screws about a main axis and to separate said polymer melt into a plurality of streams;

at least one vacuum pump adapted to maintain a pressure within said multi-screw extruder below a pressure of about 1.4 millibars as said molten recycled polymer passes through said multi-screw extruder;

a computer-controller that operates said at least one vacuum pump to reduce and maintain said pressure within said multi-screw extruder below a pressure of about 1.4 millibars during extrusion of said molten recycled polymer through said multi-screw extruder; and

a second satellite screw extruder that is mounted to rotate about a central axis of said first satellite screw and adapted to recombine said plurality of streams into a single stream.

20. The apparatus of claim **19**, wherein a number of said plurality of satellite screws is the same as a number of said plurality of streams.

21. The apparatus of claim **19**, wherein said plurality of satellite screws comprises at least eight satellite screws.

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