

POLYESTER COMPOSITIONS

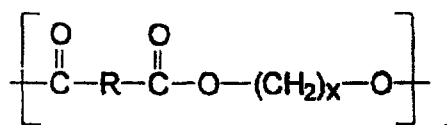
This application claims the benefit of U.S. Provisional Patent Application Patent Application Serial Number 60/021,542 filed on July 11, 1996, and is a continuation-in-part of U.S. Patent Application 08/850,168 filed on May 2, 1997, and these applications, including their claims, are specifically incorporated by reference herein.

BRIEF DESCRIPTION OF THE INVENTION

New polyester compositions containing terephthalate (T), isophthalate (I) and 2,6-naphthalate (N) moieties that are semi-crystalline and have a density of about 1.362 g/cm³ or greater are disclosed. The compositions are useful for making films, fibers and containers for packaging.

This invention is also novel semi-crystalline polyesters containing specific mole ratios of terephthalate, isophthalate and naphthalate moieties (i.e., T/I/N and T/I) useful for producing fabricated articles that exhibit unexpectedly high density levels which are typically associated with a high level of crystallinity. The high density level is achieved by strain induced crystallization, thermal crystallization, or preferably a combination of strain induced crystallization and thermal crystallization. The polyesters of this invention have enhanced performance properties, in particular they exhibit excellent gas barrier properties.

This invention is a polyester composition comprising the following repeating unit:



where in any unit x is an integer selected from 2 through 6, inclusive, and where in at least a portion of the units R is 1,3-phenyl, in at least a portion of the units R is 1,4-phenyl and in at least a portion of the units R is 2,6-naphthyl, and where the density of the polyester is at least about 1.362 g/cm³. Preferably in about 80 to about 96 mole percent of the units R is 1,4-

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phenyl, and in about 20 to about 4 mole percent of the units R is selected from 1,3-phenyl and 2,6-naphthyl where the mole ratio of 1,3-phenyl to 2,6-naphthyl is about 1:5 to about 5:1. This invention is also the polyester composition where in at least a portion of the units R is 1,4-phenyl and where
5 in at least about 5 mole percent, preferably at least about 8 mole percent, more preferably about 5 to about 25 mole percent, and most preferably about 10 to about 15 mole percent of the units in the polyester R is 1,3-phenyl, and preferably where in at least about 75 mole percent, more preferably about 75 to about 95 mole percent, and most preferably about 85 to about 95 mole
10 percent of the units R is 1,4-phenyl, and where the density of the polyester is preferably at least about 1.362 g/cm³. By 1,4-phenyl we mean a phenyl ring where the carboxylate groups of the polyester polymer unit are attached to the 1 and 4 positions of the phenyl ring, by 1,3-phenyl we mean a phenyl ring where the carboxylate groups of the polyester polymer unit are attached to
15 the 1 and 3 positions of the phenyl ring, and by 2,6-naphthyl we mean a naphthalene ring where the carboxylate groups of the polyester polymer unit are attached to the 2 and 6 positions of the naphthalene ring. Preferably, x is 2. While the preferred polyesters of this invention are those where the only polymer ester units present are those where R is 1,4-phenyl, 1,3-phenyl and
20 2,6-naphthyl, or where R is 1,4-phenyl and 1,3-phenyl; the polyesters of this invention can also contain ester units where R is some other moiety, such as an aliphatic or other type of aromatic moiety.

This invention is a polyester composition comprising terephthalate and isophthalate moieties, or comprising terephthalate, isophthalate and 2,6-
25 naphthalate moieties, which compositions have been subjected to strain induced crystallization, or a combination of strain induced and thermal crystallization. By terephthalate moiety we mean that ester unit or part of the polyester based on or derived from terephthalic acid or its equivalent; by isophthalate moiety we mean that ester unit or part of the polyester based on
30 or derived from isophthalic acid or its equivalent; and by 2,6-naphthalate moiety we mean that unit or part of a polyester molecule based on or derived from 2,6-naphthalenedicarboxylic acid or its equivalent. The equivalent of

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terephthalic acid, isophthalic acid and 2,6-naphthalic acid can be, for example, the dimethyl ester or the diacid halide.

BACKGROUND

Poly(ethylene terephthalate) (PET) has been modified with low levels of isophthalic acid (i.e., up to about 3 mole percent) primarily to adjust (decrease) the rate of crystallization of PET, in order to obtain amorphous articles such as partially oriented yarns, amorphous sheets for thermoforming or biaxially oriented film fabrication, and bottle/jar preforms for injection stretch-blow molded containers. For most applications, however, it is most desired that the final fabricated article exhibit a high level of crystallinity, typically measured by density value. Crystallinity imparts high stiffness, low creep, improved barrier properties and other desired performance properties.

There is a need to modify PET to produce fabricated articles that have a combination of high density and enhanced performance properties, such as stiffness and barrier to gases. We have discovered that PET modified with a combination of isophthalate and 2,6-naphthalate moieties provides such improved polyesters. We have also discovered that PET modified with isophthalate moieties at levels at or greater than about 5 mole percent provides such improved properties.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Disclosed herein are new polyesters comprising terephthalate (T), isophthalate (I) and naphthalate (N) moieties, preferably where the terephthalate moieties comprise about 80 to 96 mole percent of the ester units in the polyester, and preferably where isophthalate and 2,6-naphthalate moieties comprise the remaining about 20 to about 4 mole percent of the ester units. The I/N mole ratio can be about 1:5 to about 5:1. More preferred, the I/N mole ratio is about 1:2 to about 2:1. More preferably, the terephthalate moieties comprise about 83 to about 90 mole percent of the ester units. Also disclosed herein are new polyesters comprising terephthalate and isophthalate moieties wherein the isophthalate moieties

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comprise at least about 5 mole percent of the ester units, preferably about 5 to about 25 mole percent, and most preferably about 8 to about 18 mole percent of the ester units, and preferably where the terephthalate moieties comprise at least about 75 mole percent, more preferably about 75 to about 95 mole percent, and most preferably about 82 to about 92 mole percent of the ester units. The density of the polyesters of this invention, as measured, for example, using a density gradient column (ASTMD 1505-85) is advantageously at least about 1.362 g/cm^3 , preferably at least about 1.365 g/cm^3 and most preferably at least about 1.370 g/cm^3 . A polyester density of at least about 1.375 g/cm^3 and at least about 1.380 g/cm^3 can also be achieved. Preferably, the density of the polyesters of this invention is no more than about 1.455 g/cm^3 . This density can be achieved by strain induced crystallization or a combination of strain induced crystallization and thermal crystallization. The most preferred method to achieve the density level is by a combination of strain induced crystallization and thermal crystallization. Examples are: strain induced crystallization by fiber orientation followed by thermal crystallization by heat setting, strain induced crystallization by uniaxial or biaxial sheet orientation followed by thermal crystallization by heat setting, and strain induced crystallization by container injection blow molding or injection stretch-blow molding followed by thermal crystallization by heat setting.

Strain induced crystallization is a process whereby the polyester material in the form, for example, of a sheet or fiber is stretched at a suitable rate and temperature to achieve crystallization within the polyester. For strain induced crystallization useful for producing the polyester compositions of this invention, typical temperatures are about 80°C to about 140°C , typical stretch rates are about 300 to about 1500 %/second, and the stretch ratio suitable is about 8 to about 24. For fiber stretching or orientation, the stretch ratio of about 2 to about 8 is suitable.

Thermal crystallization is a process whereby the polyester is heated at a suitable temperature to induce additional crystallization and preferably where

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a stretched polyester material is retained in the stretched position and heated at a suitable temperature to induce additional crystallization. Suitable temperatures for such thermal crystallization to produce the compositions of this invention are about 100°C to about 210°C, and the articles are typically retained at this temperature for about 1 second to about 5 minutes. Heat setting is a form of thermal crystallization whereby the polyester is maintained at the selected temperature for the selected times. Heat setting can be accomplished by subjecting the polyester article to heated air or to a heated metal surface such as a mold or godet.

- 10 Thermal crystallization of a fabricated article that has been previously strain crystallized can be accomplished on a laboratory scale by subjecting an oriented sample, for example, uniaxially oriented fiber or biaxially oriented film, to heating while the specimen is constrained. The sample is constrained to prevent relaxation and shrinkage during heating and this can be
15 accomplished, for example, by fastening to a frame in the case of films or on rolls under tension for fibers.

The polyester starting materials used for making the high density polyesters of this invention can be prepared by standard melt esterification of the appropriate dicarboxylic acids in the proper mole ratio with a glycol such as
20 ethylene glycol followed by polycondensation. Alternatively, the dimethyl esters of the carboxylic acids can be transesterified with a glycol such as ethylene glycol followed by polycondensation. Typical transesterification catalysts such as the acetates of zinc, manganese, cobalt, sodium and calcium can be employed individually or in combination with each other. The
25 preferred transesterification catalyst is a combination of the acetates of cobalt and manganese. Typical polycondensation catalysts are the oxides of antimony and germanium.

The following describes a typical preparation of a 88/4.5/7.5 mole ratio T/I/N polyester using ethylene glycol as the glycol. The dicarboxylic acids in the
30 appropriate mole ratio are added as solids into a reactor, and ethylene glycol

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is added so as to have a 1.15/1.00 mole ratio of ethylene glycol/dicarboxylic acids. Tetramethylammonium hydroxide is used at a level of 38 ppm as a diethylene glycol suppressant, and a mixture of 200 ppm antimony oxide and 20 ppm of cobalt acetate are used as polycondensation catalysts. All additive and catalyst levels are by weight based on the calculated polymer yield. The polymerization consists of a pressure esterification step, an atmospheric esterification step and a vacuum polycondensation step. The pressure esterification step is performed at 40 psig and a temperature of 220-240°C for a time sufficient to remove, preferably, about 90 percent of the theoretical water by-product. Atmospheric esterification is performed at 240-260°C for 60 minutes followed by polycondensation at 270-295°C at less than 1 mm Hg vacuum level for sufficient time to reach a targeted inherent viscosity level, which is about 0.55-0.65 dL/g. The polymer can be extruded into strands, which can be cooled and chopped into pellets.

After pelletization, the molecular weight of the polymer can be increased by solid state polymerization as commonly practiced in the art. A rotary conical vacuum dryer provides a convenient means of solid state polymerizing the subject materials. In a typical procedure, the material is loaded into the dryer, rotation started, vacuum applied and the system purged with nitrogen. After purging, the system is heated to about 80°C. Once equilibrated at that temperature, the temperature is increased over a 6 hour period to about 160°C and held at that temperature for about 6 hours. The system is then cooled to room temperature, the sample dumped and any agglomerations broken up. The crystallized sample is then reloaded into the dryer, purged with nitrogen, vacuum applied to a vacuum of about 1.0 mm Hg, and the system heated to 80°C, and then the temperature is increased over a 4 hour period to 216°C. The sample is held at that temperature until the desired inherent viscosity is achieved.

The preferred inherent viscosity of the solid stated materials, as measured in 60/40 (wt/wt) phenol/tetrachloroethane at 30°C, is 0.60-1.00 dL/gm. The most preferred inherent viscosity is 0.80-0.85 dL/gm.

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Densities of samples of the polyester compositions can be increased by strain induced crystallization and further by thermal crystallization to prepare the polyester compositions of this invention. For example, 24 mil extruded sheet was made from 0.78 IV resin of the 88/4.5/7.5 T/I/N polyester composition (made using ethylene glycol as the glycol component) using a small (1½ in, 24/1 length/diameter (L/D)) Killion sheet extrusion line with a melt temperature of 300°C. Biaxially oriented film was then made from the extruded sheet using a T. M. Long film stretcher as follows. The extruded sheet was conditioned in a controlled temperature humidity room (23°C - 50% relative humidity (R.H.) for at least 24 hours prior to stretching. The preconditioned sheet sample was placed in the Long stretcher, heated for 120 seconds at 108°C and stretched biaxially 3.5 times, i.e., stretched 3.5 times the original size in each direction. Samples of the biaxially oriented film were then placed in aluminum frames having 4 inch square openings. The frames containing the film samples were then placed in a hot air oven set at a preselected temperature. The samples were removed from the oven after 5 minutes, allowed to cool to room temperature and then removed from the frames. Densities of the heat set samples were determined using the gradient column method (ASTMD 1505-85). Results for samples from the 88/4.5/7.5 T/I/N polyester composition are shown below. Other T/I and other T/I/N compositions of this invention can be prepared with different mole ratios of I and N and other glycols using the same procedure.

Sample	Density (g/cm ³)	Crystallinity (%)
Extruded Sheet	1.3364	2.9
3.5 x 3.5 Biaxially Oriented Film*	1.3600	22.7
Heat set Film (°C): 120	1.3661	27.8
150	1.3744	34.8
180	1.3767	36.7
210	1.3815	40.8

* Stretched each direction 3.5 times the original size.

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In addition to preparing these T/I or T/I/N compositions by reacting the appropriate molar ratios of terephthalic acid, isophthalic acid and 2,6-naphthalenedicarboxylic acid or their equivalents with the appropriate glycol and conducting the condensation reaction, one or more copolyesters such as an I/N copolyester or a T/N or T/I copolyester can be blended with, for example, PET in the proper amounts to form the desired T/I/N or T/I mole ratios. Thus, the polyester compositions of this invention can be prepared by blending the appropriate amounts of polyester, copolyester or terpolyester to form the desired composition, and then subjecting such compositions to strain induced crystallization and, preferably, a combination of strain induced crystallization and thermal crystallization. For example, three parts by weight of PET can be blended with one part by weight of 3/2 T/I copolyester to form a 9/1 T/I copolyester blend. Upon subjecting such blends to procedures for manufacturing film, fibers or containers, followed by strain induced crystallization and optionally followed by thermal crystallization, the high density polyester compositions of this invention can be prepared.

A wide variety of articles can be manufactured using the polyester resin compositions of this invention. For example, the polyesters of this invention can be in the form of thin, preferably planar, films which suitably have a thickness of 0.25 millimeters or less, preferably about 0.25 millimeters to about 0.02 millimeters. Such films can be used for flexible packages such as bags and wraps. The polyester of this invention can be in the form of thermoformed sheets such as blister packages, tubs and cups. Such thermoformed sheets typically have a thickness of greater than, about 0.25 millimeters, preferably a thickness of greater than about 0.25 millimeters to about 4 millimeters. The films and thermoformed sheets and other articles of this invention can be preferably made so they are optically clear and preferably with no visible haze or cloudiness. Methods for preparing and using thermoformed articles are described in "Thermoforming" by J. L. Throne, Hanser Publications (1987), which is incorporated herein by reference.

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Molded articles such as containers, and particularly containers such as bottles and jars, made from the polyester resin compositions of this invention can be manufactured by using melt molding methods. All known methods generally used for polyester molding, such as blow molding, are applicable.

5 Typical examples of usual blow molding methods are extrusion blow molding, injection blow molding, and injection stretch blow molding. Injection stretch blow molding is the preferred fabrication method. In one type of injection stretch blow molding, a hollow preform is manufactured by injection molding and the preform is cooled to ambient temperature. A preform is a precursor

10 for a container and is generally a cylinder closed at one end having a length generally about one third and an external diameter generally about one quarter of the final container made from the preform. Equipment for manufacturing preforms is available from Husky Injection Molding System and Krupp Corpoplast. The preform is then reheated to a temperature

15 typically of about 80-140°C and the heated preform is biaxially stretched in a mold in both the axial and hoop directions by blowing to form the final fabricated hollow article such as a jar or bottle. Suitable equipment for stretch blow molding is manufactured by Sidel Groupe. In another type of injection stretch blow molding, the hollow injection molded preform is made at

20 an elevated temperature then directly cooled to a temperature generally of about 80-140°C and the perform is then biaxially stretched into the final container design. Suitable equipment for this fabrication technique is manufactured by Aoki Technical Laboratory and Nissei ASB. Container stretch ratios, which are defined as the multiple of the individual axial and

25 hoop stretch ratios, of about 8-24 are advantageous for the containers of this invention, with stretch ratios of 12-21 being preferred and of 12-18 being more preferred.

The stretch ratio as used herein for the containers, in particular the bottles of this invention, can be conveniently defined as follows:

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Stretch Ratio=

$$\frac{\text{Maximum Container Diameter}}{\text{Internal Preform Diameter}} \times \frac{\text{Height of Container (without finish)}}{\text{Height of Preform (without finish)}}$$

- 5 The relationship between the preform used to make the injection stretch blow molded container, such as a bottle, and the container can also be expressed as a stretch index as follows.

Stretch Index=

$$10 \quad \frac{\text{Internal Volume of Stretched Container (excluding neck portion)}}{\text{Internal Volume of Preform Before Stretching (excluding neck portion)}} \times \frac{1}{F}$$

Where F=

$$15 \quad \frac{\text{Internal Surface Area of Stretched Container (excluding neck portions)} \text{ (cm}^2\text{)}}{\text{Internal Volume of Stretched Container (excluding neck portions)}}$$

The units of the stretch index are centimeters (cm).

The "finish" and "neck portion" in the equations above refer to the neck area or region of the preform and of the bottle or other container that is not stretched.

- 20 The containers of this invention, and particularly the bottles of this invention, have a stretch index below 130 cm, and suitably the stretch index is about 50 to 120 cm. A stretch index of about 60 cm to about 100 cm is preferred, and a most preferred stretch index is about 90 cm and lower and typically about 70 cm to about 90 cm for the containers and particularly the bottles of this invention.
- 25 A most preferred stretch index for the containers and particularly the bottles of this invention is about 85 cm and lower, and 80 cm and lower.

The containers of this invention are optically clear and preferably with no visible haze or cloudiness. The containers of this invention, and particularly the bottles of this invention, suitably have a wall thickness of the container

30 wall of about 0.12 to about 0.65 millimeters, preferably about 0.2 to about 0.45 millimeters. The inherent viscosity of the polyester in the containers and, in particular the bottles of this invention, is about 0.6 to about 1.0,

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preferably about 0.7 to about 0.9dL/g measured in a 60/40 wt/wt. phenol/tetrachlorethane at 30°C at a concentration of 0.4 g/dL.

Container mold temperatures of 10-200°C can be employed according to this invention with 60-160°C being preferred. The stretch ratio, mold temperature
5 and time at the mold temperature must be selected so as to achieve the desired density level. The strain induced crystallization is achieved during the stretch blow molding process and, if used, thermal crystallization, or heat setting, is achieved by the contact of the container with the metal mold at the preselected temperatures and for the preselected times to achieve the
10 desired polyester density. The time the container is in contact with the mold is suitably about 1 to 8 seconds, preferably about 2 to about 5 seconds.

One of the advantages of this invention is that containers and particularly bottles can be manufactured without the necessity of adding crystallization accelerants or crystallization retardants. Other standard additives, such as
15 thermal stabilizers, light stabilizers, dyes, pigments, plasticizers, fillers, antioxidants, lubricants, effusion aids, residual monomer scavengers and the like can be optionally added. However, it is not necessary to add other monomers, such as chain terminating monomers, to the polyesters used to make the containers and, particularly the bottles, of this invention.

20 The T/I and T/I/N compositions of this invention may be used for preparing fibers, films and rigid containers. The films and containers show improved processability, strength and gas permeability characteristics. Improved gas permeability is particularly useful for films used in packaging and for bottles and other containers.

25 The polyester compositions of this invention demonstrate excellent gas barrier properties particularly for carbon dioxide and oxygen. These excellent gas barrier properties make the polyesters of this invention highly suitable for manufacturing bottles and other containers used to package carbonated water and carbonated beverages as well as water and non-carbonated
30 beverages. Small bottles, for example 20 oz. and less such as 12 oz., 1 liter,

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0.5 liter and 0.33 liter bottles, made from the polyester of this invention have excellent shelf life properties. The films, sheets and containers of this invention preferably have carbon dioxide permeability values measured at 35°C of no more than about 30, preferably no more than about 25, more preferably no more than about 22 and most preferably no more than about 20 cc-mil/100 in² day atm.

The polyester containers of this invention, and particularly the bottles of this invention containing polyester having terephthalate, isophthalate and 2,6-naphthalate moieties in the proportions described hereinabove, and those containing polyester having terephthalate and isophthalate moieties in the proportions described hereinabove, can be manufactured by improved injection stretch blow molding processes due to the superior performance properties of the terephthalate, isophthalate and naphthalate polyesters, and the terephthalate and isophthalate polyesters. Thus, in preform injection molding processes, lower temperatures and shorter cycle times can be employed. For example, preform molding temperatures of about 250°C to about 290°C, preferably about 260°C to about 275°C can be used. We have also determined that containers of this invention have low levels of acetaldehyde. If acetaldehyde levels are too high, poor taste properties are imported to the materials such as water and beverages, contained within the bottle or other container. In measurements on the preforms used to make the containers of this invention, the preforms containing either terephthalate, isophthalate and 2,6-naphthalate moieties in the amounts described hereinabove, or those containing terephthalate and isophthalate moieties in the amounts described hereinabove, where ethylene glycol is the glycol portion of the polyester, the acetaldehyde content is less than about 8 micrograms per gram of preform, preferably less than about 6 micrograms per gram of preform, and most preferably less than about 5. Preforms containing less than about 4.5 micrograms of acetaldehyde per gram of preform are also made by this invention. The amount of acetaldehyde in the preform is measured by grinding a sample of the preform that has been cooled to liquid nitrogen temperature and then passing the ground preform

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through a 20 mesh sieve. A 0.1 gram sample of the sieved material is placed in a 8 milliliter capped vial and the vial is heated in a heat block at 150°C for 30 minutes. A sample of the headspace, typically a one milliliter sample, in the vial is analyzed by gas chromatography for acetaldehyde content. The result is reported as milligrams of acetaldehyde per gram of preform.

Containers of this invention, particularly the bottles of this invention, containing either terephthalate, isophthalate and 2,6-naphthalte moieties in the amounts described hereinabove, or those containing terephthalate and isophthalate moieties in the amounts described hereinabove, and where ethylene glycol is the glycol portion of the polyester, have acetaldehyde levels less than about 3 micrograms of acetaldehyde per liter of container internal volume, preferably less than about 2.5 micrograms, and more preferably less than about 2.0 micrograms, and most preferably less than about 1.5 micrograms of acetaldehyde per liter of container internal volume. The level of acetaldehyde in the container is measured by ASTM D 4509-85.

The polyester containers and particularly the bottles of this invention can be manufactured to a variety of shapes and sizes including those known to those of skill in the art. One such bottle is depicted in Figure 1. The bottle 1 in Figure 1 includes a threaded finish or neck portion 2, an optional handling ledge 3, which is integral with and downwardly depending from the threaded finish portion 2 and further includes an outwardly sloping shoulder portion 4, which is integral with and downwardly depending from the handling ledge 3. A main body portion, or sidewall portion 5, is integral with and downwardly depending from the shoulder 4. A closed bottom portion 6 is formed integral with and downwardly depending from the main body portion 5 and serves to completely close the bottom of the polyester bottle. The closed bottom portion can also be in the so-called "petaloid" form.

Descriptions of polyester preforms and polyester bottles and general methods for their manufacture are provided in PCT Patent Application WO 96/33062 published on October 24, 1996, which is incorporated herein by reference.

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Methods for making polyester fibers are disclosed in, for example, "Polyester-50 Years of Achievement," published by The Textile Institute, Manchester, England, printed in Dewsbury, England in 1993 by Stanley Press, and in "Wellington Sears Handbook of Industrial Textiles," by E. R. Kaswell,
 5 Wellington Sears Co., 1963, both of which publications are specifically incorporated herein by reference.

Table 1 shows the density and percent crystallinity of 3.5 x 3.5 biaxially oriented films of the 88/4.5/7.5 mole ratio T/I/N polyester composition (ethylene glycol as the glycol component) and the effect of heat setting to
 10 increase density.

Table 2 shows the CO₂ permeability of 3.5 x 3.5 biaxially oriented films of the 88/4.5/7.5 T/I/N composition (ethylene glycol as the glycol component), non-heat set and heat set, compared to biaxially oriented films from PET and polyethylene naphthalate (PEN) homopolymers. The percent decrease in
 15 CO₂ permeability relative to that for the non-heat set PET film is shown.

Tables 1 and 2 show that T/I/N polyester compositions of this invention have improved density, crystallinity and CO₂ barrier properties compared to PET.

Glycols useful in preparing the compositions of this invention include glycols having 2 to 6 carbon atoms, inclusive, such as glycols of the structure:

20 HO — (CH₂)_x — OH, where x = 2 - 6, inclusive.

Preferably, the glycol used is ethylene glycol, i.e. where x = 2.

TABLE 1

88/4.5/7.5 T/I/N Polyester Biaxially Oriented Film Heat Set 5 Minutes

3.5 x 3.5 Film	Density (g/cm ³)	Increase (%)	Crystallinity (%)
No Heat set (°C):	1.3600		22.7
120	1.3661	0.45	27.8
150	1.3744	1.06	34.8
180	1.3767	1.23	36.7
210	1.3815	1.58	40.8

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TABLE 2

CO₂ Permeability of Heat Set Films

Composition	Heat Set (H.S.)	Density (g/cm ³)	Cryst. (%)	CO ₂ Permeability*	% CO ₂ Permeability Decrease Relative to PET**
PET ^a	No HS	1.3661	27.1	30.0	—
PET ^a	210/5 ^d	1.3884	45.4	28.4	5.3
88/4.5/7.5 ^b	No HS	1.3600	22.7	26.3	12.3
88/4.5/7.5 ^b	120/5 ^d	1.3661	27.8	23.4	22.0
88/4.5/7.5 ^b	210/5 ^d	1.3815	40.8	21.2	29.3
PEN ^c	No HS	1.3468	26.6	4.9	83.7

* cc-mil/100 in²-day-atm at 35°C

** non-heat set PET

^a polyethylene terephthalate^b mole ratio: terephthalate/isophthalate/naphthalate in T/I/N^c polyethylene naphthalate^d °C for number of minutes

EXAMPLES

Crystallinity values reported herein were calculated from the density values, which were measured using the ASTM D-1505-85 procedure. Carbon dioxide (CO₂) permeability values were measured using the method described by T. L. Caskey in "Modern Plastics," page 148 (1967).

Example 1

For the preparation by melt polymerization of a 88/4.5/7.5 T/I/N terpolymer, the following reactants were added to a 56 liter batch reactor made of 316 stainless steel equipped with a helical anchor agitator rotating 52 rpm: ethylene glycol (16,523 grams), terephthalic acid (33,841 grams), isophthalic acid (1,731 grams), 2,6-naphthalenedicarboxylic acid (3,754 grams), 10% by weight of a tetramethylammonium hydroxide solution in water (17.19 grams), antimony trioxide (10.86 grams), and cobalt acetate (3.83 grams). The reactor was purged with nitrogen and the reactor was pressurized with nitrogen to 40 psig. The oil heating fluid used to heat the reactor had been heated to 121°C and when the contents of the reactor reached 107°C, the start of pressure esterification was recorded. The oil temperature was increased to 274°C in order to maintain a melt temperature (i.e., the temperature of the contents of the reactor) of 260°C, and the pressure was maintained at 40 psig by the release and condensation of water vapor. After 230 minutes, 7,130 grams of condensate was collected and the pressure was reduced over a period of 5 minutes to atmospheric pressure.

The atmospheric esterification step was conducted for 60 minutes at a melt temperature of 263°C and 370 grams of condensate was collected. Fifty minutes after the start of the atmospheric esterification step, a mixture of 3.38 grams of phosphoric acid dissolved in 100 grams of ethylene glycol was added to the polymer melt. At the termination of the atmospheric esterification step, the oil temperature was increased so as to maintain a melt temperature of 274-288°C and the pressure was reduced at a rate of about

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25 mm Hg/minute to about 1.0 mm Hg vacuum level. As the melt viscosity of the terpolyester increased, the speed of the agitator was reduced step-wise in 5 rpm increments to 20 rpm. Polycondensation was continued for 233 minutes when the targeted torque of 2500 pound/inch was achieved at 20 rpm agitator speed.

The vacuum was released with nitrogen and 50 psig pressure of nitrogen was added to the reactor. The polymer was extruded into strands by the use of a melt pump on the bottom of the reactor. The strands were cooled in a water bath and chopped into amorphous pellets. The pellets had a 0.60 dL/g inherent viscosity as measured in 60/40 wt/wt phenol/tetrachloroethane at 30°C at a concentration of 0.4 g/dL. Isolated product yield was 37,000 grams.

Example 2

Sixty-five pounds of the amorphous pellets from Example 1 were placed in a 70 liter rotary conical vacuum reactor with oil heat transfer fluid heated to 176°F. Vacuum was applied (0.5 mm Hg) and the reactor was rotated at a speed of 2 rpm. The oil temperature was increased over a period of 4.0 hours at a rate of 0.4°F/minute to a final temperature of 320°F. The pellets were crystallized at this temperature for 6.0 hours. The temperature was cooled to ambient, nitrogen was used to release the vacuum and the crystallized pellets were sieved to remove any agglomerated pellets. The yield of sieved pellets was 64 pounds.

Example 3

Sixty-four pounds of the crystalline pellets from Example 2 were placed in a 70 liter rotary conical vacuum reactor with oil heat transfer fluid heated to 170°F. Vacuum was applied (0.5 mm Hg) and the reactor was rotated at a speed of 2 rpm. The oil temperature was increased over a period of 4.0 hours at a rate of 1.0°F/minute to a final temperature of 410°F. Solid state polymerization was continued for 18 hours, the temperature was cooled to ambient, nitrogen was used to release the vacuum and the solid state

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polymerized pellets were sieved to remove any agglomerated pellets. The yield of sieved pellets was 62 pounds, and the pellets had an inherent viscosity (IV) of 0.78 dL/g.

Example 4: Extruded Sheet Preparation

- 5 Extruded sheet from Example 3 was made from 0.78 IV resin of the 88/4.5/7.5 T/I/N polyester composition using a Killion Model KL-125 1¼ inch, 24/1 L/D single screw extruder equipped with a 6 inch flexible lip sheet extrusion die and a 3 roll sheet take-off unit. Temperature setting in zones 1 through 6 (feed to exit) were 268, 274, 277, 277, 277 and 260°C. Melt
10 temperature was 300°C. Screw speed was 75 rpm and take-up speed was 5.5 feet/minute. The temperature of cooling water to the 3 rolls of the take-off unit was 38°C. Under these conditions, 24 mil thick extruded sheet having a density of 1.3364 g/cm³ was produced.

Example 5: Biaxially Oriented Film Preparation

- 15 Biaxially oriented film was made from the 24 mil 88/4.5/7.5 T/I/N polyester extruded sheet using a T. M. Long film stretcher. Sample 2¼ inch squares were die cut from extruded sheet prepared as described in Example 4 above and conditioned in a controlled temperature humidity room (23°C - 50% R.H.) for 24 hours prior to stretching. The conditioned sheet samples were placed
20 in the Long stretcher heated for 120 seconds at 108°C and stretched biaxially at a strain rate of 300% per second to final dimensions in each direction 3.5 times greater than the starting dimensions. The density of the resulting 3.5 x 3.5 biaxially oriented film was 1.3600 g/cm³.

Example 6: Heat Setting of Biaxially Oriented Film

- 25 Heat setting was done using an aluminum frame having two 4 inch square openings. A sample of biaxially oriented film was placed in each opening of the frame, and the frame containing the samples was placed in a hot air oven set at a preselected temperature. The samples were removed from the oven after 5 minutes, allowed to cool at room temperature and then removed from
30 the frames. Densities of the heat set samples were determined using the

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gradient column method (ASTMD 1505-85). Densities of 3.5 x 3.5 biaxially oriented films from the 88/4.5/7.5 T/I/N polyester compositions prepared as described in the above examples are shown below.

Sample	Density (g/cm ³)	Increase in Density (%)
Extruded Sheet	1.3364	—
3.5 x 3.5 Biaxially Oriented Film	1.3600	1.8
Heat set Film (°C): 120	1.3661	2.2
150	1.3744	2.8
180	1.3767	3.0
210	1.3815	3.4

5 Example 7

For the preparation by melt polymerization of PETI-10 copolymer (polyethylene terephthalate modified with 10 mole percent isophthalate moieties, i.e., a 9/1 T/I), the following reactants were added to a 56-liter 316 stainless steel batch reactor equipped with a helical anchor agitator rotating at 52 rpm: ethylene glycol (16,860 grams), terephthalic acid (35,290 grams), isophthalic acid (3,920 grams), 10% by weight of a tetramethyl-ammonium hydroxide solution in water (11.2 grams), antimony trioxide (10.86 grams), and cobalt acetate (3.83 grams). The reactor was purged with nitrogen and the reactor was pressurized with nitrogen to 40 psig. The oil heating fluid used to heat the reactor had been heated to 121°C and when the contents of the reactor reached 107°C, the start of pressure esterification was recorded. The oil temperature was increased to 274°C in order to maintain a melt temperature of 260°C, and the pressure was maintained at 40 psig by the release and condensation of water vapor. After 230 minutes, 7,475 grams of condensate was collected and the pressure was reduced a period of 5 minutes to atmospheric pressure.

The atmospheric esterification step was conducted for 60 minutes at a melt temperature of 263°C and 420 grams of condensate was collected. Fifty minutes after the start of the atmospheric esterification step, a mixture of

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- 3.38 grams of phosphoric acid dissolved in 100 grams of ethylene glycol was added to the polymer melt. At the termination of the atmospheric esterification step, the oil temperature was increased so as to maintain a melt temperature of 274-285°C and the pressure was reduced at a rate of about 25 mm Hg/minute to about 1.0 mm Hg vacuum level. As the melt viscosity of the copolyester increased, the speed of the agitator was reduced step-wise in 5 rpm increments to 20 rpm. Polycondensation was continued for 225 minutes when the targeted torque of 2500 pound/inch was achieved at 20 rpm agitator speed.
- 10 The vacuum was released with nitrogen and 50 psig pressure of nitrogen was added to the reactor. The polymer was extruded into strands by the use of a melt pump on the bottom of the reactor. The strands were cooled in a water bath and chopped into amorphous pellets. The pellets had a 0.65 dL/g inherent viscosity as measured in 60/40 wt/wt phenol/tetrachlorethane at 15 30°C at a concentration of 0.4 g/dL. Isolated product yield was 37,290 grams.

Example 8

- Sixty-five pounds of PETI-10 from the above Example 7 were crystallized and solid state polymerized in a manner similar to that described in Examples 2 and 3. The times, temperatures, and vacuum levels were identical to the previous examples. The yield of sieved pellets was 61 pounds, and the pellets had an inherent viscosity of 0.81 dL/g.

The other compositions of this invention can be made using the procedures of Examples 1-7, inclusive.

25 Example 9

T/I and T/N copolyesters and T/I/N terpolyesters were melt polymerized in a manner similar to that described in Examples 1 and 7. The melt polymerized inherent viscosity values for the compositions and PET homopolymer are shown in Table 3.

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TABLE 3

Summary of T/I/N Compositions

Composition (T/I/N)*	I/N Ratio	Inherent Viscosity (dL/g)		
		Melt Polymerized	Solid State Polymerized	Extruded Sheet
PET	—	0.62	0.76	0.73
8.0 Mole Percent Modified				
PETN-8 ^a	—	0.61	0.80	0.75
92/4.0/4.0	1/1	0.61	0.78	0.73
92/5.3/2.7	2/1	0.61	0.81	0.79
10.0 Mole Percent Modification				
PETI-10 ^b	—	0.65	0.81	0.78
12.0 Mole Percent Modification				
PETN-12 ^a	—	0.64	0.80	0.78
88/4.0/8.0	1/2	0.60	0.81	0.80
88/8.0/4.0	2/1	0.61	0.81	0.78
16.0 Mole Percent Modification				
PETN-16 ^a	—	0.58	0.78	0.73
84/5.3/10.7	1/2	0.60	0.81	0.76
84/8.0/8.0	1/1	0.62	0.80	0.76
PETI-16 ^b	—	0.64	0.84	0.79

* Ethylene glycol is the glycol component.

^a PETN-8, 12, 16 means a polyethylene terephthalate-naphthalate copolyester having 8, 10 and 16 mole percent naphthalate moieties, i.e., a T/N.

^b PETI-10 and PETI-16 means a polyethylene terephthalate-isophthalate copolyester having 10 mole percent isophthalate and 16 mole percent isophthalate, respectively, i.e., a T/I.

10 **Example 10**

T/I and T/N copolyesters and T/I/N terpolyesters from Example 9 were crystallized and solid state polymerized in a manner similar to that described in Examples 2 and 3. The solid state polymerization inherent viscosity values for the compositions and for PET homopolymer are shown in Table 3.

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Example 11

T/I and T/N copolyesters and T/I/N terpolyesters from Example 10 were extruded into sheet in a manner similar to that described in Example 4. The sheet inherent viscosity values for the compositions and for PET homopolymer are shown in Table 3.

Example 12

T/I and T/N copolyesters and T/I/N terpolyesters sheets from Example 11 were biaxially oriented into 3.0 x 3.0 biaxially oriented film in a manner similar to that described in Example 5. The films were then heat set in a manner similar to that described in Example 6. The initial sheet density and crystallinity, and the film density, density increase, crystallinity, carbon dioxide permeability, and carbon dioxide barrier improvement compared to PET are shown in Table 4 for both non-heat set film (no HS) and film heat set at 210°C for 5 minutes (HS 210/5). The units for the carbon dioxide permeability (Perm.) values are cc-mil/100 in²-day-atm. The percentages shown for CO₂ permeability are the percentages for the change in CO₂ permeability relative to PET.

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TABLE 4

Film Properties

PET	Sheet	3 x 3 no HS	3 x 3 HS 210/5
Density g/cm ³	1.3376	1.3670	1.3885
% Increase	—	2.20	3.81
% Cryst.	3.8	27.9	45.5
CO ₂ Perm.	—	35.8	30.5
PETN-8^a			
Density g/cm ³	1.3364	1.3626	1.3830
% Increase	—	1.96	3.49
% Cryst.	3.7	25.7	42.9
CO ₂ Perm.	—	30.2 (-15.6%)	25.8 (-15.4%)
92/4/4 T/I/N			
Density g/cm ³	1.3379	1.3653	1.3835
% Increase	—	2.05	3.41
% Cryst.	3.6	26.3	41.4
CO ₂ Perm.	—	29.9 (-16.5%)	24.6 (-19.3%)
92/5.3/2.7 T/I/N			
Density g/cm ³	1.3376	1.3631	1.3835
% Increase	—	1.91	3.43
% Cryst.	3.0	24.3	41.3
CO ₂ Perm.	—	28.7 (-19.8%)	24.8 (-18.7%)
PETN-12^a			
Density g/cm ³	1.3362	1.3622	1.3764
% Increase	—	1.95	3.01
% Cryst.	3.6	25.8	37.9
CO ₂ Perm.	—	28.5 (-20.4%)	25.0 (-18.0%)
88/4.5/7.5 T/I/N			
Density g/cm ³	1.3368	1.3615	1.3785
% Increase	—	1.85	3.12
% Cryst.	3.2	23.9	38.2
CO ₂ Perm.	—	32.0 (-10.6%)	25.0 (-18.0%)

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TABLE 4

Film Properties (cont'd)

88/8/4 T/I/N	Sheet	3 x 3 no HS	3 x 3 HS 210/5
Density g/cm ³	1.3366	1.3634	1.3805
% Increase	--	2.01	3.28
% Cryst.	1.8	24.1	38.3
CO ₂ Perm.	—	26.8 (-25.1%)	19.6 (-35.7%)
PETI-10^b			
Density g/cm ³	1.3383	1.3620	1.3839
% Increase	—	1.77	3.41
% Cryst.	3.9	23.4	41.3
CO ₂ Perm.	—	27.7 (-22.6%)	19.8 (-35.1%)
PETN-16^a			
Density g/cm ³	1.3350	1.3601	1.3761
% Increase	—	1.88	3.08
% Cryst.	2.6	24.3	38.1
CO ₂ Perm.	—	26.6 (-25.7%)	23.0 (-24.6%)
84/5.3/10.7 T/I/N			
Density g/cm ³	1.3360	1.3617	1.3772
% Increase	--	1.92	3.08
% Cryst.	2.5	24.3	37.5
CO ₂ Perm.	—	25.1 (-29.9%)	22.0 (-27.9%)
84/8/8 T/I/N			
Density g/cm ³	1.3361	1.3608	1.3771
% Increase	--	1.85	3.07
% Cryst.	1.8	22.5	36.2
CO ₂ Perm.	—	25.2 (-29.6%)	20.8 (-31.8%)
PETI-16^b			
Density g/cm ³	1.3374	1.3601	1.3789
% Increase	—	—	—
% Cryst.	0.6	19.2	34.6
CO ₂ Perm.	—	24.2 (-32.4%)	21.0 (-31.1%)

^a PETN-8, 12, 16 means a polyethylene terephthalate-naphthalate copolyester having 8, 10 and 16 mole percent naphthalate moieties, i.e., a T/N.

5 ^b PETI-10 and PETI-16 means a polyethylene terephthalate-isophthalate copolyester having 10 mole percent and 16 mole percent isophthalate, respectively i.e., a 9/1 T/I and a 84/16 T/I.

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Example 13

T/I and T/N copolyesters and T/I/N terpolyesters from Example 11 were biaxially oriented into 4 x 4 biaxially oriented film in a manner similar to that described in Example 5. The sheet and film densities, percent density increase and film crystallinity values are shown in Table 5.

TABLE 5
4 x 4 Film Properties

Density g/cm ³					
Composition T/I/N ^a	I/N Ratio	Sheet	Film	Increase (%)	Film Crystallinity (%)
PET	—	1.3376	1.3702	2.44	30.5
8.0 Mole Percent Modification					
PETN-8 ^b	—	1.3364	1.3671	2.30	29.5
92/4.0/4.0	1/1	1.3379	1.3674	2.20	28.1
92/5.3/2.7	2/1	1.3376	1.3689	2.34	29.1
10.0 Mole Percent Modification					
PETI-10 ^b	—	1.3383	1.3673	2.17	27.7
12.0 Mole Percent Modification					
PETN-12 ^a	—	1.3362	1.3666	2.28	29.6
88/4.0/8.0	1/2	1.3368	1.3659	2.18	27.6
88/8.0/4.0	2/1	1.3366	1.3657	2.18	26.0
16.0 Mole Percent Modification					
PETN-16 ^a	—	1.3350	1.3613	1.97	25.3
84/5.3/10.7	1/2	1.3360	1.3625	1.98	25.0
84/8.0/8.0	1/1	1.3361	1.3621	1.95	23.6
PETI-16 ^b	—	1.3374	1.3635	1.95	22.0

^a PETN-8, 12, 16 means a polyethylene terephthalate-naphthalate copolyester having 8, 10 and 16 mole percent naphthalate moieties, i.e., a T/N.

^b PETI-10 and PETI-16 means a polyethylene terephthalate-isophthalate copolyester having 10 mole percent isophthalate and 16 mole percent isophthalate, respectively, i.e., a 9/1 T/I and a 84/16 T/I.

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Example 14

Preforms (52.5 grams) designed for a straight wall 2 liter stretch blow molded bottle were injection molded from 0.80 IV PET control resin, 0.89 IV PETI-10 resin, and 0.81 IV 88/8/4 mole ratio T/I/N resin on an Arburg 320H single cavity injection molding machine. Temperature profiles and cycle times were as shown below.

(Temperature, °C)	PET	PETI-10	88/8/4
Nozzle	275	260	260
Front Zone	285	270	265
Middle Zone	285	270	265
Rear Zone	275	255	255
Cycle Time, sec.	39.0	33.9	33.9

Two liter straight wall bottles were stretch blow molded on a Krupp Corpoplast LBO 1 stretch blow molding machine from these preforms. The preforms from all the compositions were heated to 105°C prior to stretch blow molding.

Density and percent crystallinity of samples taken from the sidewall of the 2 liter bottles as molded and after heat setting at 160°C for 2.5 seconds are shown below. Also shown are carbon dioxide permeability of non-heat set sidewall samples and estimated shelf life based on carbonation retention of whole bottles.

Bottle Sidewall Properties

Non-Heat Set	PET	PETI-10	88/8/4
Density g/cm ³	1.3700	1.3640	1.3610
Crystallinity (%)	30.4	23.8	22.1
After Heat Setting			
Density g/cm ³	1.3768	1.3715	1.3705
Crystallinity (%)	35.9	29.9	30.0
CO₂ Permeability on Whole Bottle			
Estimated Shelf Life in Weeks	11.7	14.5	
% Improvement in CO ₂ Permeability Over PET	—	+24	

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These data show the excellent CO₂ gas barrier properties achieved by the polyester compositions of this invention.

Example 15

- 5 Provided in the table below are the results of the analysis for acetaldehyde levels of bottle preforms and bottles made from PET, a PETI-10 and an 88/8/4 T/I/N. The bottles were 12 oz. bottles made from a 21.7 gram injection molded preform by injection stretch blow molding. The molding temperature, shown below is the temperature used for the preform molding. The cycle
- 10 time is the time for resin injection into the mold, molding and ejection of the preform.

	PET	PETI-10	88/8/4 T/I/N
Molding Temp. (°C)	275-280	255-265	250
Cycle Time (sec)	29.6	27.4	27.4
Acetaldehyde (ppm)			
Resin ^a	1.0	0.4	0.5 micrograms per gram of resin
Preform ^a	10.5	5.2	4.3 micrograms per gram of preform
Bottle Headspace ^b	2.9	1.3	1.1 micrograms per liter bottle volume

a Acetaldehyde levels measured using the procedure described herein above for measuring acetaldehyde levels in preforms.

b Measured using a procedure based on ASTM D 4509-85.

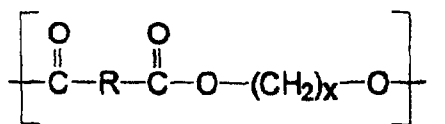
15

These data demonstrate that the method of this invention produces preform and bottles having low levels of undesirable acetaldehyde.

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CLAIMS

Having described the invention, that which is claimed is:

1. A polyester composition comprising the following repeating units



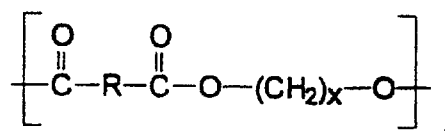
- 5 where in any unit X is an integer selected from 2 through 6, inclusive, and where in at least a portion of the units R is 1,4-phenyl, and where in at least about 5 mole percent of the total units R is 1,3-phenyl, and where the density of the polyester is at least about 1.362 g/cm³.
2. The polyester of Claim 1 wherein about 8 to about 25 mole
10 percent of the total units R is 1,3-diphenyl.
3. The polyester of Claim 1 wherein at least about 75 mole percent of the total units R is 1,4-diphenyl.
4. The polyester of Claim 1 wherein X is 2.
5. Articles of manufacture comprising the polyester of Claim 1.
- 15 6. Containers comprising the polyester of Claim 1 having a stretch index of less than 130 cm.
7. Fibers comprising the polyester of Claim 1.
8. Films comprising the polyester of Claim 1.
9. A polyester composition comprising terephthalate moieties and
20 at least about 8 mole percent isophthalate moieties having a density of at least about 1.362 g/cm³.
10. A polyester composition comprising terephthalate moieties and at least about 5 mole percent isophthalate moieties which composition has been subjected to a combination of strain induced and thermal crystallization.



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11. Containers comprising the polyester of Claim 9.
12. Containers comprising the polyester of Claim 10.
13. The polyester containers of Claim 11 made by injection stretch blow molding using a stretch ratio of about 21 and lower.
- 5 14. The polyester containers of Claim 12 made by injection stretch blow molding using a stretch ratio of 21 and lower.
15. A method for making high density polyester comprising subjecting a polyester composition comprising the following repeating units



- 10 to strain induced crystallization and optionally followed by thermal crystallization to achieve a density of the polyester of at least about 1.362 g/cm³, where in any unit x is an integer selected from 2 through 6, inclusive, and where in at least a portion of the units R is 1,4-phenyl, and wherein at least about 5 mole percent of the total units R is 1,3-phenyl.
- 15 16. The method of Claim 15 wherein the strain induced crystallization is accomplished in a container stretch blow molding apparatus.
17. The polyester of Claim 9 wherein the mole ratio of terephthalate to isophthalate moieties is 92:8 to about 82:18.
18. A polyester container manufactured by blow molding of a
20 preform wherein the polyester comprises terephthalate moieties and at least about 8 mole percent isophthalate moieties and wherein the container has a stretch index of less than 130 cm.
19. The container of claim 18 wherein the mole ratio of terephthalate to isophthalate moieties is about 92:8 to about 82:18.
- 25 20. The container of Claim 18 in the form of a bottle.
21. A polyester preform for injection stretch blow molding wherein the polyester comprises terephthalate moieties and isophthalate moieties and



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having a level of acetaldehyde less than about 8 micrograms per gram of preform.

22. The preform of Claim 21 wherein the mole ratio of terephthalate to isophthalate moieties is about 95:5 to 75:25.

5 23. A polyester preform for injection stretch blow molding wherein the polyester comprises terephthalate moieties, isophthalate moieties and 2,6-naphthalate moieties and having a level of acetaldehyde less than about 8 micrograms per gram of preform.

10 24. A polyester container comprising terephthalate moieties and at least about 8 mole percent isophthalate moieties and having a level of acetaldehyde less than about 8 micrograms of acetaldehyde per liter of container volume.

15 25. A polyester container comprising terephthalate moieties, isophthalate moieties and 2,6-naphthalate moieties having a level of acetaldehyde less than about 8 micrograms of acetaldehyde per liter of container volume.

26. The bottle of Claim 20 having a stretch index of about 90 cm and lower.

20 27. The bottle of Claim 20 having a stretch index of about 85 cm and lower.

28. The bottle of Claim 20 having a stretch index of about 80 cm and lower.

25 29. The bottle of Claim 20 containing a liquid selected from the group consisting of water, a beverage, carbonated water and carbonated beverage.



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