A process of chemically densifying polystyrene comprises the steps of creating a densifying system comprising at least one densifying reagent and contacting polystyrene with said densifying solution. Densified polystyrene can be reclaimed by creating a reclamation system comprising at least one solubilizing reagent, dissolving the densified polystyrene in said reclamation system, precipitating the polystyrene from the resulting solution and separating the precipitated and purified polystyrene from the solution. The products of the densification and reclamation processes can be altered by varying the reagents and solvents, and their relative concentrations. The products can include an oil, a gel, a gum, a hard, miniaturized version of the original form, or a granular or fibrous product. Paint, ink and/or contaminants can be removed from plastics by the addition of an abrasive to the densifying solution and/or reclamation solution.

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CHEMICAL DENSIFICATION AND RECLAMATION OF POLYSTYRENE

Mary Jo Brandt

This is a non-provisional application based upon an earlier-filed Provisional Application, Serial Number 60/038,996, filed November 27, 1996.

BACKGROUND OF THE INVENTION

This invention pertains to a method of reducing the volume of polystyrene. More particularly, it pertains to a method of chemically densifying polystyrene. Even more particularly, it pertains to a method of chemically densifying expanded polystyrene (EPS).

The invention also pertains to a method of reclaiming polystyrene polymer after densification. More particularly, it pertains to a method of purifying the densified polystyrene. Even more particularly, it pertains to a method of reclaiming polystyrene by ranges of molecular weight.

The invention further pertains to products that result from the chemical densification, the reclamation and separation process and to the chemical compounds used to densify, reclaim and separate polystyrene by ranges of molecular weights.

The invention also pertains to a method of removing paint, ink or contaminants from plastic during densification and/or reclamation. It also pertains to a method of facilitating the separation of the densified plastic from contaminant solids.

Polystyrene, particularly expanded polystyrene, is a widely used material. The lightweight foam is used for food containers, insulation and packaging materials, particularly as filler for excess space in packing boxes, e.g. polystyrene "peanuts".

Expanded polystyrene foam is particularly well suited as a packaging
material because it is lightweight, with a density of approximately 0.2 lbs/ft³. However, once it has been discarded, the lightweight expanded polystyrene presents an environmental and recycling problem. To date, there is no economical way to recycle expanded polystyrene. Most recyclers are compensated on a per pound basis. The volume of expanded polystyrene necessary to make an economical quantity makes recycling impractical. Therefore, expanded polystyrene typically goes directly to landfills. Polystyrene, a very stable polymer, maintains its form in the landfills. Its large volume per weight takes up a disproportionate amount of space for its weight in a landfill and adds to the structural instability of the landfill.

Current methods of volume reduction include mechanical compression, which relies on molecular creep to maintain compaction, such as is described in U.S. Patent 5,505,886, Baugh et al., issued April 9, 1996. Because of polystyrene's "memory", either an extended period of applied pressure and/or use of very high pressures are required to overcome this "memory" and to achieve maintained compaction. This mechanical approach requires expensive equipment, industrial settings and relatively high energy consumption. It is not feasible to perform compression for volume reduction at the site of discard of post-consumer EPS. Other densification methods employ shearing, chopping, heat and/or organic solvents. None of these methods addresses the need for cost effective transportation as a requisite starting point in order to have competitively priced recycled material. An additional benefit from reclaiming expanded polystyrene and purifying it without development of a heat history is that the reclamation obviates the need for synthesis of the polymer from styrene, as well as obviating the synthesis of styrene from feedstocks of benzene and ethylene. Reclamation of polystyrene reduces the consumption of irreplaceable natural resources, e.g., petroleum, and decreases the use of energy sources used in the synthesis of the polymer.

Sorting and washing of contaminated polystyrene add to the cost of recycling. Current methods of polystyrene reclamation also often rely on heating of solutions containing the polymer to high temperatures or on heating the polymer directly. This causes degradation of the polymer and a lower purity of the
reclaimed product. Some methods use organic solvents that are toxic and highly regulated, e.g., benzene.

It would be desirable to have a safe, low energy-consuming process whereby the volume of expanded polystyrene foam could be significantly reduced so that transporting it to a recycling facility from any point of public discard would be economical. Furthermore, it would be desirable to have a process that uses little or no energy and utilizes chemicals and processes that are safe for the environment and for the workers who are exposed to them. It would also be desirable to be able to reclaim relatively pure polystyrene from contaminated post-consumer, commercial and industrial discard. It would also be desirable to separate the densified polystyrene from contaminants after the process of densification, thereby eliminating manual separation and sorting of contaminated, expanded polystyrene.

The present invention provides a method of densifying polystyrene by contacting it with chemicals, preferably chemicals that are substantially environmentally safe. The densification method of the present invention does not require the addition of heat to the polystyrene. Thus, the chemical densification method of the present invention minimizes the degradation of the starting polystyrene molecule. It also provides a more homogeneous polystyrene product than other methods, thereby expanding the market for the recycled product.

Additionally, the method of reclamation of the densified polystyrene permits its use on food-contaminated polystyrene mixed with other forms of reclaimed polystyrene and allows for the separation of mixed molecular weight polystyrene after densification. This provides a more homogeneous polystyrene product than other methods expanding the marketability of the recycled product, and eliminates the need for pre-densification separation, or sorting.

The present invention also provides a method for removing the paint or ink from polystyrene surfaces during the process of densification. It is also desirable to have a method for removing inks and paints from the EPS as part of the process of densification and purification and to be able to separate the post-consumer contaminants from the crude densified polystyrene without the use of heat or unsafe
reagents. Further, the present invention provides a physico-chemical method for facilitating the separation of the densified plastic from the contaminating solids. Precipitation of purified, densified polystyrene into narrow ranges of molecular weights can produce select products for use in further applications.

**SUMMARY OF THE INVENTION**

The present invention provides a method of chemically densifying polystyrene comprising the steps of:

- creating a densifying system comprising at least one densifying reagent; and, contacting polystyrene with said densifying system.

In another aspect, the present invention provides a method of reclaiming purified polystyrene comprising the steps of:

- densifying polystyrene;
- creating a reclamation system comprising at least one solubilizing reagent;
- dissolving the densified polystyrene in said reclamation system to form a reclamation solution;
- precipitating the densified polystyrene from the reclamation solution with a precipitating reagent; and,
- separating the precipitated polystyrene from the reclamation solution.

The present invention further provides products created by the chemical densification of polystyrene and the reclamation of densified polystyrene. These products can vary from an oil to a granular or fibrous material, depending on the constituents of the densifying system and the reclamation system.

The invention further provides a densifying system for densifying polystyrene comprising at least one densifying reagent.

The invention further provides a reclamation system and precipitating reagent for reclaiming purified, densified polystyrene.

The invention further provides a method of removing paint, ink and contaminants from polystyrene.
DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides a method of chemically densifying polystyrene by creating a densifying system and contacting polystyrene with the densifying system.

The densifying system comprises at least one densifying reagent. The densifying reagent can be selected from the group consisting of substituted benzenes, cyclic hydrocarbons, terpenes and terpenoids, aryl and alkyl ethers, aryl and alkyl aldehydes, aryl and alkyl ketones, linalool, organic acids, naturally occurring citrus oils, and combinations thereof. Naturally occurring citrus oils are those that are obtained from the skins of citrus fruits, whether subjected to further processing or not. Preferably the substituted benzenes are selected from the group consisting of anisoles, including alkyl substituted anisoles, alkenyl substituted, and vinyl substituted anisoles anisoles (such as anethole and allyl anethole); phenols, including alkyl substituted phenols, alkenyl substituted phenols (such as eugenol), and vinyl substituted phenols; anisaldehydes; benzaldehydes; anisic acid; 4-methoxybenzyl alcohol; cinnamaldehyde; alkyl substituted benzenes, including xylene and toluene; and combinations thereof. Preferably the cyclic hydrocarbons are selected from the group consisting of cyclohexanes; cyclohexenes; and substituted cyclic hydrocarbons, including hydroxy substituted cyclic hydrocarbons, methoxy substituted cyclic hydrocarbons, alkyl substituted hydrocarbons (such as menthol), and alkenyl substituted hydrocarbons. Preferably the terpenes and terpenoids are selected from the group consisting of dipentene, limonene, pinene, geranial (also known as citral), menthol, myrcene, farnesene, zingiberene, selinene, caryophyllene, squalene, carotene, terpene ethers (such as cineole, also known as eucalyptol), and combinations thereof. Preferably the alkyl ether is diethyl ether. Preferably the aryl and alkyl aldehydes are selected from the group consisting of anisaldehydes, such as anisaldehyde; benzaldehyde; cinnamaldehyde; citral, also known as geranial or geranialdehyde; citronellal, also known as d-rhodinal. Preferably the organic acid is anisic acid or cinnamic acid. Commercially available
or naturally occurring citrus oils may be used as a densifying reagent. More than one densifying reagent may be used in combination with any other densifying reagent to make the densifying system.

An antioxidant agent may be added to the densifying reagent to retard or prevent oxidation and increase the duration of activity and potency of the densifying reagent. Preferably the antioxidant agent is tocopherol, carotene, or vitamin A, or organic salts of these.

A densifying reagent may be selected for properties in addition to its ability to densify polystyrene. For example, anisole and limonene exhibit antimicrobial properties that may be beneficial when densifying polystyrene that has been exposed to food or other sources of microorganisms.

To aid in the removal of paints, inks and contaminants on the polystyrene, the densifying system may further comprise at least one abrasive. Suitable abrasives can be, but are not limited to, washed sand, finely ground glass or fired clay (bisque), and combinations thereof.

The densifying system must be a liquid. The densifying system may consist essentially of a densifying reagent, if the densifying reagent is a liquid. However, it is preferable that the densifying system further comprise at least one densifying solvent.

The densifying solvent can be selected from the group consisting of water, alkanols, triols, mineral oil, vegetable oils, terpenes and terpenoids, aryl ethers, and combinations thereof. Preferably, the solvent is selected from the group consisting of water, C_{1-6} alkanols, glycerol, mineral oil, vegetable oils, terpenes, aryl ethers, and combinations thereof.

If a densifying solvent is used, the densifying solvent and densifying reagent are brought into contact with one another and mixed thoroughly to form the densifying system. Any method of mixing known in the art can be used, including, but not limited to, stirring and shaking. If an abrasive is used, it may be added to the densifying system at any time prior to contacting the polystyrene with the densifying system.
The densifying system can be brought into contact with the polystyrene by any method known in the art including spraying the densifying system onto the polystyrene, or immersing the polystyrene in the densifying system. It is important that the densifying system contact the polystyrene. There is no limitation on how this contact is accomplished.

The densifying system can be contacted with the polystyrene at room temperature. Depending on the densifying reagent(s) and densifying solvent(s) chosen, heat may be added to increase the rate and extent of densification. However, it is preferable that the contacting occur at temperatures less than 95°C. The less heat that is added to the polystyrene, the less "heat history" the molecule has and the less degradation than occurs in the molecule.

The polystyrene should be kept in contact with the densifying system until densification is complete. The amount of time required is dependent on the densifying reagent(s), the densifying solvent(s), the relative concentrations of densifying reagent(s) and densifying solvent(s) in the densifying system, the starting density of the expanded polystyrene, the presence of mechanical agitation of the polystyrene and densifying system, and the temperature at which contacting occurs. The time necessary for densification will be readily determinable by one skilled in the art. The densification can occur at any atmospheric pressure. Preferably, the densification takes place at ambient or greater than ambient pressure.

Preferably, the polystyrene and densifying system are agitated while they are contacted. Agitation can be provided by any means known in the art, including but not limited to, shaking and/or stirring.

The products that result from the densification process can be varied depending upon the densifying reagent(s) used, the densifying solvent(s) used, and the relative concentrations of densifying reagent(s) and densifying solvent(s) in the densifying system. The products can include an oil, which upon drying becomes a pliable, hard plastic. A gel or a gum can be produced. Fibers and miniaturized versions of the starting form can also be produced. When utilizing xylenes as the densifying reagent and alkanol(s) as the densifying solvent, granular or fibrous...
particles can result. The range of products available from the densification process will be described in more detail in the following examples:

Example 1

Polystyrene oil was produced by the chemical densification process of the present invention. EPS was contacted with densifying solution in a Pyrex beaker. The densifying system comprised 50% by volume anisole in light mineral oil. The densifying solution contacted the EPS for less than 60 seconds at room temperature (approximately 27°C) and ambient pressure (approximately 760 mm Hg). The starting density of the EPS was approximately 0.003 gm/cc.

Example 2

Hard pliable polystyrene plastic was produced by the chemical densification process of the present invention. EPS was contacted in a Pyrex beaker with a densifying system comprising 33% by volume p-anisaldehyde in 80% n-propanol diluted with glycerin at room temperature and ambient pressure for less than 10 seconds. The resulting densified product was dried at room temperature. The starting density of the EPS was approximately 0.003 gm/cc. The density of the hard, pliable polystyrene plastic was greater than 0.700 gm/cc.

Example 3

Polystyrene gel was produced by the chemical densification process of the present invention. EPS was contacted in a Pyrex beaker with a densifying system comprising 33% by volume trans-anethole in 80% isopropanol diluted with glycerin for less than 30 seconds at room temperature and ambient pressure. The starting density of the EPS was approximately 0.003 gm/cc. The density of the polystyrene gel was greater than 0.800 gm/cc.

Example 4

Polystyrene gum was produced by chemical densification process of the
present invention. EPS was contacted in a Pyrex beaker with a densifying system comprising 4M anisole in light mineral oil for less than 60 seconds at room temperature and ambient pressure. The starting density of the EPS was approximately 0.003 gm/cc. The density of the polystyrene gum was greater than 0.800 gm/cc.

Example 5

Miniaturized peanuts, which maintained the original shape of the starting EPS packing peanuts, were produced by the chemical densification process of the present invention. EPS peanuts were contacted in a Pyrex beaker with a densifying system comprising 3M anisole in light mineral oil for more than one hour at room temperature and ambient pressure. The starting density of the EPS peanuts was approximately 0.003 gm/cc.

Example 6

Fibrous strands of polystyrene were produced by the chemical densification of the present invention. EPS was contacted in a Pyrex beaker with a densifying system comprising 33% by volume l-limonene suspension in 80% isopropanol diluted with glycerin for less than 15 seconds at room temperature and ambient pressure. The starting density of the EPS was approximately 0.003 gm/cc.

Example 7

A clear, very thin cellophane-like sheet of polystyrene was produced by chemical densification process of the present invention. EPS was contacted in a Pyrex beaker with a densifying system comprising commercial lime oil for less than 15 seconds at room temperature and ambient pressure. The starting density of the EPS was approximately 0.003 gm/cc. The density of the cellophane-like sheet of polystyrene was greater than 0.500 gm/cc.

In another aspect, the present invention provides a method of reclaiming purified polystyrene. Polystyrene is first densified by any method, including
mechanical methods and chemical methods. Suitable mechanical methods include
compression, such as that described in U.S. Patent 5,505,886, Baugh et al., issued
April 9, 1996 and incorporated herein by reference. Suitable chemical methods
include the chemical densification method of the present invention, as well as the
method disclosed in U.S. Patent 5,223,543, Iovino, issued June 29, 1993,
incorporated herein by reference. Densified polystyrene is solubilized in a
reclamation system comprising at least one solubilizing reagent to create a
reclamation solution. Polystyrene is then precipitated from the reclamation solution
by the addition of a precipitating reagent. The purified, precipitated polystyrene is
then separated from the reclamation solution.

The reclamation system contains at least one solubilizing reagent. The
solubilizing reagent is selected from the group consisting of substituted benzenes,
cyclic hydrocarbons, terpenes and terpenoids, aryl and alkyl ethers, aryl and alkyl
aldehydes, aryl and alkyl ketones, linalool, organic acids, naturally occurring citrus
oils, and combinations thereof. Preferably the substituted benzenes are selected
from the group consisting of anisoles, including alkyl substituted anisoles, alkenyl
substituted anisoles, and vinyl substituted anisoles (such as anethole and allyl
anethole); phenols, including alkyl substituted phenols, alkenyl substituted phenols
(such as eugenol), and vinyl substituted phenols; anisaldehyde; anisic acid; 4-
methoxybenzyl alcohol; cinnamaldehyde; alkyl substituted benzenes, including
xylenes and toluene; and combinations thereof. Preferably the cyclic hydrocarbons
are selected from the group consisting of cyclohexanes; cyclohexenes; and
substituted cyclic hydrocarbons, including hydroxy substituted cyclic hydrocarbons,
methoxy substituted cyclic hydrocarbons, alkyl substituted hydrocarbons (such as
menthol), and alkenyl substituted hydrocarbons. Preferably the terpene and
terpenoids are selected from the group consisting of dipentene, limonene, pinene,
geranial (also known as citral), menthol, myrcene, farnesene, zingiberene, selinene,
caryophyllene, squalene, carotene, terpene ethers (such as cineole, also known as
eucalyptol), and combinations thereof. Preferably the alkyl ether is diethyl ether.
Preferably the aryl and alkyl aldehydes are selected from the group consisting of
anisaldehydes; benzaldehyde; cinnamaldehyde; citral, also known as geranial or geranialdehyde; citronellal, also known as d-rhodinal. Preferably the organic acid is anisic acid or cinnamic acid. More than one solubilizing reagent may be used in combination with any other solubilizing reagent to make the reclamation system.

The reclamation system may further comprise at least one abrasive. The abrasive can be, but are not limited to, sand, finely ground glass or fired clay (bisque), and combinations thereof.

The reclamation system may further comprise a reclamation solvent. The reclamation solvent can be selected from the group consisting of substituted benzenes, cyclic hydrocarbons, terpenes and terpenoids, alkyl and aryl ethers, alkyl and aryl aldehydes, aryl and alkyl ketones, organic acids, mineral oil, water, and combinations thereof. Preferably, the substituted benzenes are selected from the group consisting of anisoles, including alkyl substituted anisoles, alkenyl substituted anisoles, and vinyl substituted anisoles (such as anethole and allyl anethole); phenols, including alkyl substituted phenols, alkenyl substituted phenols (such as eugenol), and vinyl substituted phenols and alkyl substituted benzenes, including xylene and toluene. Preferably, the cyclic hydrocarbons are selected from the group consisting of cyclohexanes; cyclohexenes; and substituted cyclic hydrocarbons, including hydroxy substituted cyclic hydrocarbons, methoxy substituted cyclic hydrocarbons, alkyl substituted cyclic hydrocarbons (such as menthol), and alkenyl substituted cyclic hydrocarbons. Preferably, the terpenes and terpenoids are selected from the group consisting of dipentene; limonene; pinene; myrcene; farnesene; caryophyllene; squalene; and terpene ethers, such as cineole (also known as eucalyptol). Preferably, the alkyl ether is diethyl ether. Preferably, the aryl and alkyl aldehydes are selected from the group consisting of anisaldehydes; benzaldehyde; cinnamaldehyde; citral (also known as geranial or geranialdehyde); and citronellal (also known as d-rhodinal). Preferably, the aryl and alkyl ketones are ethyl acetates or carvone. Preferably, the organic acids are anisic acid, cinnamic acid or erucic acid.

The densified polystyrene is precipitated with a precipitating reagent that is
more soluble in the reclamation system than is the polystyrene. Preferably, the precipitating reagent is selected from the group consisting of glycerols, alkanols, water, mineral oils or vegetable oils.

The precipitated polystyrene can be separated from the reclamation solution by any means known in the art, including, but not limited to, decanting, centrifuging and filtering. Preferably, the dissolving, precipitating and separating is performed at temperatures less than 95° C. Vacuum may be used in the process of reclamation. The reclaimed polystyrene can be in different forms, including oil, gum, hard plastic and fibrous material, depending on the constituents of the densifying system and their relative concentrations, the extent of densification, the constituents of the reclamation system and their relative concentrations, and the precipitating reagent.

The polystyrene-containing reclamation solution can be added to the precipitating reagent rather than adding the precipitating reagent to the polystyrene solution. The polystyrene solution can be added to the precipitating reagent by spraying, extrusion, pouring or any other means of contacting the solubilized polystyrene with the precipitating reagent. The size, form and consistency of the precipitated polystyrene can be varied by the method of contacting chosen.

Water may be added to the reclamation system after precipitation of the formerly solubilized polystyrene. The water can form an interface between the polystyrene and the contaminant-sediment (the abrasive and any contaminating foods and beverages), thus forming a three-phase system. The water solubilizes any water-soluble contaminants.

The abrasive may be mixed or agitated when added, or placed on top of the plastic which allows centrifugation alone to carry it through the crude plastic to trap contaminants and abrade the plastic on its way to the bottom of the container holding the polystyrene.

The method of the present invention may be used to densify,solubilize, remove print, ink, or other contaminants from, and/or reclaim other plastics, particularly polycarbonates.
The methods of the present invention can also be used to scent articles or have the densified polystyrene act as an inert carrier or delivery device for vermicides and pesticides. It appears that the densifying system becomes entrapped in the densified product that results from the chemical densification method described above. Some of the reagents, particularly the terpenes, ketones and aldehydes are constituents of essential oils and have a pleasant odor or have commercial uses for their scent. For example, limonene smells like lemons, anisole and anetholes smell like anise, pinene smells like pine and citronellal is used to ward off insects. The densified products retain the odor of these reagents on their interior surfaces even after washing with warm water and soap, and rinsing with alcohol. The products can be used in their densified form, or they can be fashioned into another shape to provide a scented article that can be used in any item wherein a scent is desired. Such products can include, but are not limited to, home or car air fresheners, closet or drawer sachets, and, in the case of citronellal, to replace citronella candles and to ward off insects. Other articles with less pleasant odors may also be used to repel animals or insects, e.g., around gardens or in garages, etc. Polystyrene containing anisole and limonene can exhibit insecticidal properties, particularly in closed spaces.

The method of the reclamation process produces purified polystyrene plastics in oil, gum, fibrous or hard plastic form of varied ranges of molecular weight. The polystyrene can be separated into narrow or broad ranges of molecular weights by fractional precipitation using a precipitating reagent. The purified, precipitated polystyrene can be used directly or after further processing to form expanded polystyrene or hard plastic products.

Partial solubilization can result in fractional separation of polystyrene by molecular weights. The lower molecular weight polystyrenes are likely the first to be solubilized and can be separated with centrifugation, just as the highest molecular weights are the first to be precipitated at a later step. This differential solubilization would allow an earlier separation by molecular weights before a second purification by solubilization step.
Example 8

Densification and reclamation of EPS and removal of paint, ink and food contaminants from the EPS was performed on approximately one pound (454 grams) of EPS using the process of the present invention. The entire process was performed at room temperature and ambient pressure.

Densification and Reclamation

Approximately one (1) pound (454. + grams) of expanded polystyrene articles were processed. The articles were white, except for a blue egg carton. Several of the pieces had ink and/or paint on them.

A contaminant material was made from 1058 grams of food, beverages, cigarette butts and ashes [total volume approx. 1000 ml]. The specific foods represented all major food groups. The material was converted to a brown frappe-like material and applied to each piece of expanded polystyrene (EPS). The contaminated EPS was allowed to dry approximately 15 hours. The EPS filled an 80 L container.

The densifying system was 1.4 liters of densifying solution of 50:50 anisole:light mineral oil by volume. This was applied by spray (340 cc) and pouring with mechanical agitation (shaking) during addition. No antioxidant was used. The densification began immediately upon spraying. Some of the densifying solvent-reagent was poured down the side of the container and the column of EPS sank into it. Periodically, the container was mechanically agitated to hasten the process. The agitation was not necessary to the process. The overall densification was complete in 22 minutes with mechanical agitation.

The contents of the 80 L container were transferred to a smaller container and mechanically agitated with added sand [approx. 150 cc by vol].

Recovery

The contents of the smaller container [approx. 3 liters] were separated into
centrifuge containers and the contents centrifuged at 5000 RPM for 5 minutes in a Sorvall refrigerated centrifuge with temperature maintained at 28 to 30 C°.

The recovered layers after centrifugation from top to bottom were:

a. Golden-orange, slightly cloudy liquid [densifying system + contaminants] [1050 cc]
b. Crude polystyrene plastic with some adherent paint and ink remaining. [1000cc]
c. Dark liquid [water and contaminants][170cc]
d. Food and sand admixed [700 cc]
e. Sand

The polystyrene plastic was treated as follows:

a. Crude polystyrene plastic [ivory colored with paint & food remnants] was removed from the centrifuge container and transferred to a larger container for the process of purification by solubilization.

Purification

The crude densified polystyrene was placed in an approximately 16L bucket. To this mixture was added 2000 ml of anisole in 500 ml increments with intermittent stirring. Approximately 150 cc by volume of sand was added and further stirred. The partially solubilized polystyrene was a tangerine/melon orange color.

A 47 ml aliquot of the crude polystyrene in anisole was removed from the crude plastic-anisole-sand mixture after agitation to a homogeneous appearance.

To the 47 ml aliquot, approximately 120 ml anisole was added with stirring until the liquid had decreased in opacity to a semi-translucent yellow with grossly visible debris.

The solubilized polystyrene in anisole was centrifuged at 5000 RPM sustained for 5 minutes.

The supernatant pale yellow liquid was visibly cleared and tan debris, paint, and sand comprised the bottom layer.
The pale yellow supernatant was decanted [approximately 150 ml]. To this was added isopropanol with stirring. At the addition of 75 ml of isopropanol, a white precipitate formed and persisted. The precipitate was removed and set on aluminum foil. An additional 170 ml of isopropanol was added to the remaining anisole-polystyrene solution with precipitation of a large volume of white material that settled to the bottom of the beaker. The liquid remained pale yellow.

The precipitates were centrifuged at 5000 RPM for 5 minutes and the supernatant decanted. The white polystyrene precipitate was again centrifuged at 7500 RPM for 10 minutes, releasing another 5 ml of liquid as a supernatant.

The total volume of recovered white polystyrene was approximately 10 ml of viscous polystyrene oil/gum from an estimated 15.7 ml maximum of PS that would have been in the starting tangerine colored, partially solubilized crude polystyrene. It was estimated that at least 60 to 65% of the polystyrene was recovered without having given it a heat history. The polystyrene oil was snow white.

Only one solubilization for purification was performed. It may be that only one solubilization is necessary. When the crude or purified solutions of anisole-polystyrene are applied as thin films on aluminum foil, a plastic piece can form. After a period of evaporation of the solubilizing reagent, the polystyrene is converted from a liquid of varying viscosity to a plastic film of varying malleability.

Additional Recoveries

Some of the crude partially solubilized polystyrene was dropped from a stirring rod into a beaker containing isopropanol. Polystyrene precipitated in the isopropanol as a bubble about the size of a champagne grape.

The orange densifying system retained its ability to solubilize or densify EPS after it had been used and recovered.

A 100 ml aliquot of the used densifying solvent reagent [originally 50:50 anisole:light mineral oil] was distilled at 94-96°C, ambient pressure, over 100 ml of distilled water and a water-cooled condenser. The water layer was brought to a boil. The distillate was a 2-phase recovery. The top layer of distillate was a
colorless, clear anisole, a drop of which promptly solubilized a small piece of EPS. The bottom layer was a colorless cloudy liquid. Approximately 19ml of anisole was recovered [minimum recovery of anisole (densifying reagent) = 19ml/50ml starting = 38%]. The distillation was stopped before completion.

As the distillation proceeded and anisole was recovered, a cream-white layer formed at the interface between the water and orange densifying solvent-reagent liquid in the distillation flask. This layer may be some part of the polystyrene that was solubilized by the densifying solvent-reagent system. A fine plastic-like ivory colored film also deposited on the upper surface of the distillation flask above the level of the orange densifying solvent-reagent liquid. This, too, is likely polystyrene and could be recovered. The orange upper layer gradually became cloudy. The bottom water layer also became cloudy.

In summary, numerous benefits have been described that result from employing the concepts of the present invention. The foregoing descriptions have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obvious modifications or variations are possible in light of the above teachings. The embodiments were chosen and described in order to best illustrate the principles of the invention and its practical applications, so as to thereby enable one of ordinary skill in the art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.
What is claimed is:

1. A method of chemically densifying polystyrene comprising the steps of: creating a densifying system comprising at least one densifying reagent; and, contacting polystyrene with said densifying system.

2. A method according to claim 1 wherein said densifying reagent is selected from the group consisting of substituted benzenes, cyclic hydrocarbons, terpenes and terpenoids, aryl and alkyl ethers, aryl and alkyl aldehydes, aryl and alkyl ketones, linalool, organic acids, naturally occurring citrus oils, and combinations thereof.

3. A method according to claim 2 wherein said substituted benzene is selected from the group consisting of anisoles; anetholes; allyl anetholes; phenols; anisaldehyde; benzaldehyde; anisic acid; 4-methoxybenzyl alcohol; cinnamaldehyde; alkyl substituted benzenes; xylenes; toluene; and combinations thereof.

4. A method according to claim 2 wherein said cyclic hydrocarbon is selected from the group consisting of cyclohexanes; cyclohexenes; and substituted cyclic hydrocarbons.

5. A method according to claim 2 wherein said terpene and terpenoids are selected from the group consisting of dipentene, limonene, pinene, geranial, menthol, myrcene, farnesene, zingiberene, selinene, caryophyllene, squalene, carotene, terpene ethers, cineole, and combinations thereof.

6. A method according to claim 2 wherein said alkyl ether is diethyl ether.

7. A method according to claim 2 wherein said aryl and alkyl aldehydes are selected from the group consisting of anisaldehydes; benzaldehyde; cinnamaldehyde; citral; and citronellal.

8. A method according to claim 2 wherein said organic acid is anisic acid, cinnamic acid, or combinations thereof.

9. A method according to claim 1 wherein said densifying system further comprises an antioxidant agent.

10. A method according to claim 1 wherein said densifying system
consists essentially of a densifying reagent.

11. A method according to claim 1 wherein said densifying system further comprises a densifying solvent.

12. A method according to claim 11 wherein said densifying solvent is selected from the group consisting of water, alkanols, triols, mineral oil, vegetable oils, terpenes and terpenoids, aryl ethers, and combinations thereof.

13. A method according to claim 12 wherein said densifying solvent is selected from the group consisting of water, C_{14} alkanols, glycerol, mineral oil, vegetable oils, terpenes, aryl ethers, and combinations thereof.

14. A method according to claim 1 wherein said contacting occurs at or below a temperature of about 95°C.

15. A method according to claim 1 wherein said densifying system further comprises at least one abrasive.

16. A method according to claim 15 wherein said at least one abrasive is selected from the group consisting of sand, finely ground glass, finely ground fired clay, and combinations thereof.

17. An oil made in accordance with the process of claim 1 wherein said densifying system comprises about 50% by volume anisole and the balance is light mineral oil.

18. A pliable hard plastic made in accordance with the process of claim 1 wherein said densifying system comprises about 33% by volume anisaldehyde and the balance is a solution of about 80% by volume n-propanol and about 20% by volume glycerin and further comprising the step of drying the densified polystyrene.

19. A gel made in accordance with the process of claim 1 wherein said densifying system comprises about 33% by volume trans-anethole and the balance is a solution of about 80% by volume isopropanol and about 20% by volume glycerin.

20. A gum made in accordance with the process of claim 1 wherein said densifying system comprises about 4M anisole in light mineral oil.
21. A hard miniaturized product made in accordance with the process of claim 1 wherein said densifying system comprises about 3M anisole in light mineral oil.

22. A granular or fibrous product made in accordance with the process of claim 1 wherein said densifying system comprises about 33% by volume l-limonene suspended in a solution of about 80% by volume isopropanol and about 20% by volume glycerin.

23. A clear thin cellophane-like product made in accordance with the process of claim 1 wherein said densifying system comprises lime oil

24. A process of densifying polystyrene according to claim 1 wherein said polystyrene is expanded polystyrene.

25. A method of reclaiming purified polystyrene comprising the steps of:
  densifying polystyrene;
  creating a reclamation system comprising at least one solubilizing reagent;
  dissolving the densified polystyrene in said reclamation system to form a reclamation solution;
  precipitating the densified polystyrene from the reclamation solution with a precipitating reagent; and,
  separating the precipitated polystyrene from the reclamation solution.

26. A method according to claim 25 wherein said densifying is accomplished by a mechanical method or a chemical method.

27. A method according to claim 26 wherein said chemical method comprises the steps of:
  creating a densifying system comprising at least one densifying reagent; and,
  contacting polystyrene with said densifying system.

28. A method according to claim 25 wherein said solubilizing reagent is is selected from the group consisting of substituted benzenes, cyclic hydrocarbons, terpenes and terpenoids, aryl and alkyl ethers, aryl and alkyl aldehydes, aryl and alkyl ketones, linalool, organic acids, naturally occurring citrus oils, and combinations thereof.
29. A method according to claim 28 wherein said substituted benzene is selected from the group consisting of anisoles; anetholes; allyl anetholes; phenols; anisaldehyde; anisic acid; 4-methoxybenzyl alcohol; cinnamaldehyde; alkyl substituted benzenes; xylenes; toluene; and combinations thereof.

30. A method according to claim 28 wherein said cyclic hydrocarbon is selected from the group consisting of cyclohexanes; cyclohexenes; substituted cyclic hydrocarbons; and combinations thereof.

31. A method according to claim 28 wherein said terpene and terpenoid are selected from the group consisting of dipentene, limonene, pinene, geranial, menthol, myrccene, farnesene, zingiberene, selinene, caryophyllene, squalene, carotene, terpene ethers, cineole, and combinations thereof.

32. A method according to claim 28 wherein said alkyl ether is diethyl ether.

33. A method according to claim 28 wherein said aryl and alkyl aldehydes are selected from the group consisting of anisaldehydes; benzaldehyde; cinnamaldehyde; citral; citronellal; and combinations thereof.

34. A method according to claim 28 wherein said organic acid is anisic acid, cinnamic acid, or combinations thereof.

35. A method according to claim 25 wherein said reclamation system further comprises at least one abrasive.

36. A method according to claim 35 wherein said at least one abrasive is selected from the group consisting of sand, finely ground glass, finely ground fired clay, and combinations thereof.

37. A method according to claim 25 wherein said reclamation system further comprises a reclamation solvent.

38. A method according to claim 37 wherein said reclamation solvent is selected from the group consisting of substituted benzenes, cyclic hydrocarbons, terpenes and terpenoids, aryl and alkyl ethers, aryl and alkyl aldehydes, aryl and alkyl ketones, linalool, organic acids, and combinations thereof.

39. A method according to claim 38 wherein said substituted benzene is
selected from the group consisting of anisoles; phenols; alkyl substituted benzenes; and combinations thereof.

40. A method according to claim 38 wherein said cyclic hydrocarbon is selected from the group consisting of cyclohexanes; cyclohexenes; substituted cyclic hydrocarbons; and combinations thereof.

41. A method according to claim 38 wherein said terpene and terpenoid are selected from the group consisting of dipentene, limonene, pinene, myrcene, farnesene, caryophyllene, squalene, terpene ethers, and combinations thereof.

42. A method according to claim 38 wherein said alkyl ether is diethyl ether.

43. A method according to claim 38 wherein said aryl and alkyl aldehydes are selected from the group consisting of anisaldehydes; benzaldehydes; cinnamaldehyde; citral; and citronellal.

44. A method according to claim 38 wherein said organic acid is anisic acid, cinnamic acid, erucic acid, or combinations thereof.

45. A method according to claim 38 wherein said aryl and alkyl ketones are ethyl acetates, carvones, or combinations thereof.

46. A method according to claim 25 wherein said precipitating reagent is selected from the group consisting of glycerols, alkanols, water, and combinations thereof.

47. A method according to claim 25 wherein said dissolving, precipitating and separating is performed at or below a temperature of about 95°C.

48. A method according to claim 25 further comprising the step of adding water to said reclamation system after addition of said precipitating reagent and before separating the precipitated polystyrene.

49. A method according to claim 25 wherein only densified polystyrene in a particular molecular weight range is dissolved in said reclamation system.

50. A method according to claim 25 wherein only dissolved densified polystyrene in a particular molecular weight range is precipitated from the reclamation solution.
51. A method of reclaiming plastic comprising the steps of:
creating a reclamation system comprising at least one solubilizing
reagent and at least one abrasive;
solving the plastic in said reclamation system to form a reclamation
5 solution;
precipitating the plastic from the reclamation solution with a precipitating
reagent; and,
separating the precipitated plastic from the reclamation solution.
52. A method according to claim 51 wherein said plastic is
polycarbonate.
### INTERNATIONAL SEARCH REPORT

**A. CLASSIFICATION OF SUBJECT MATTER**

| IPC 6 | C08J11/08 |

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

| Minimum documentation searched (classification system followed by classification symbols) |
| IPC 6 | C08J |

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

**Date of the actual completion of the international search**

25 March 1998

**Date of mailing of the international search report**

07/04/1998

**Name and mailing address of the ISA**

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Authorized officer

Hallemeesch, A

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