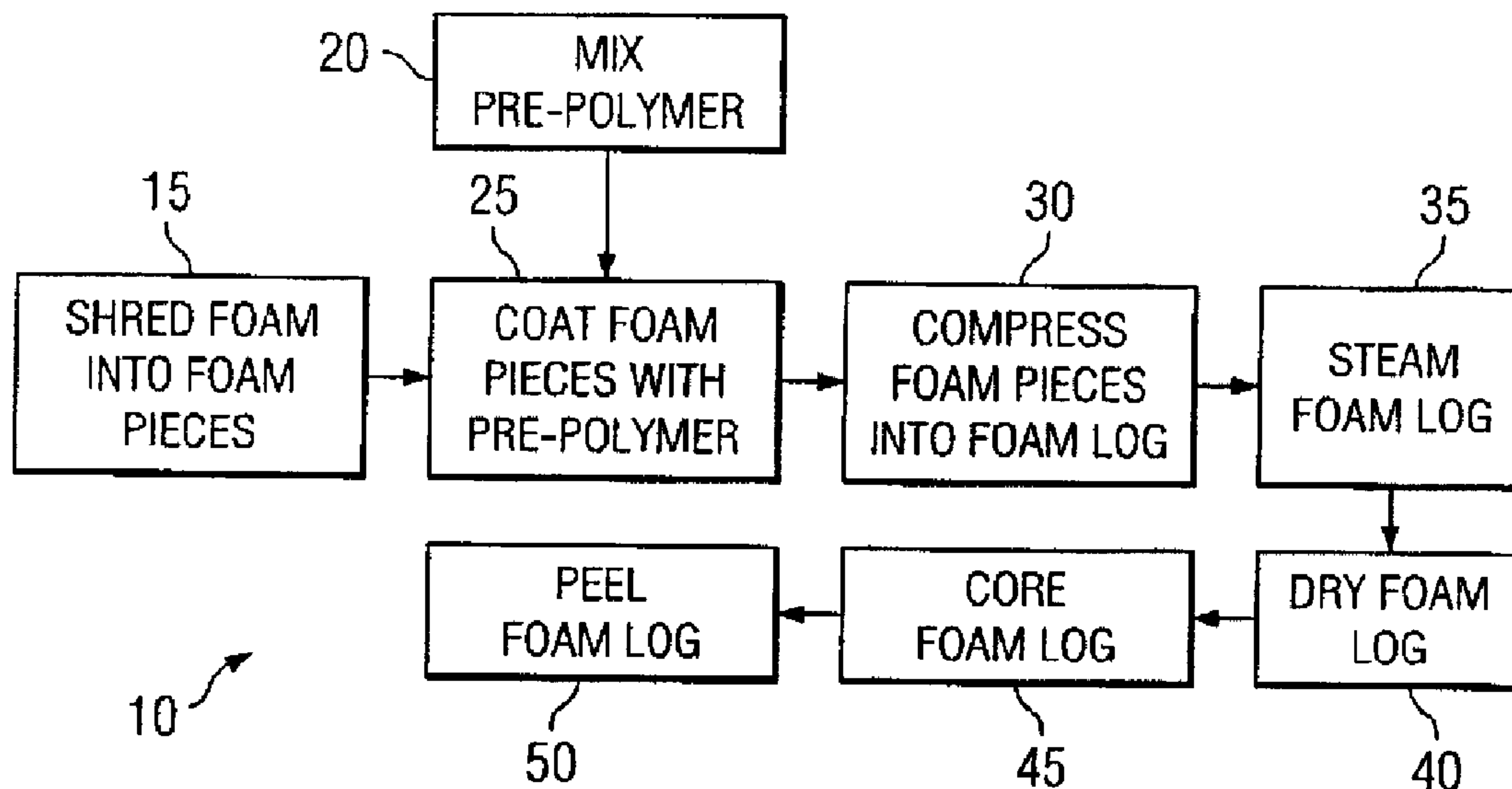




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(54) Titre : PRODUIT A BASE DE MOUSSE DE POLYURETHANE OBTENU A PARTIR POLYOL D'HUILE VEGETALE ET METHODE POUR LE PRODUIRE
 (54) Title: POLYURETHANE FOAM PRODUCT MANUFACTURED WITH VEGETABLE OIL POLYOL AND METHOD FOR MANUFACTURING



(57) **Abrégé/Abstract:**

A bonded foam product manufactured with a vegetable oil polyol is herein disclosed. The pre-polymer for use as a binder in the manufacture of a bonded foam product comprises an isocyanate and a vegetable oil polyol, wherein the pre-polymer is substantially free of any petrochemical polyol. In another aspect, the invention is method for making a bonded foam product, the method comprising coating a plurality of foam pieces with a pre-polymer, the pre-polymer comprising an isocyanate and a vegetable oil polyol, wherein the pre-polymer is substantially free of any petrochemical polyol, compressing the foam pieces into a foam log of a desired density, and steaming the foam log to cure the pre-polymer. If desired, a process oil may be added to the pre-polymer to modify the viscosity of the pre-polymer. A polyurethane foam created from a formulation comprising from about 1 percent to about 70 percent of a vegetable oil polyol is disclosed. The polyurethane foam is made from a formulation comprising an isocyanate, a surfactant, and a polyol blend comprising a vegetable oil polyol. Also disclosed is a polyurethane foam made from a formulation comprising a polyol blend comprising a petrochemical polyol and a vegetable oil polyol, and an isocyanate blend comprising a 2, 4 toluene diisocyanate (TDI) isomer and a 2, 6 TDI isomer, wherein the ratio of petrochemical polyol to vegetable oil polyol in the polyol blend is about equal to the ratio of the 2, 4 TDI isomer to the 2, 6 TDI isomer in the isocyanate blend.



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ABSTRACT OF THE DISCLOSURE

A bonded foam product manufactured with a vegetable oil polyol is herein disclosed. The pre-polymer for use as a binder in the manufacture of a bonded foam product comprises an isocyanate and a vegetable oil polyol, wherein the pre-polymer is substantially free of any petrochemical polyol. In another aspect, the invention is method for making a bonded foam product, the method comprising coating a plurality of foam pieces with a pre-polymer, the pre-polymer comprising an isocyanate and a vegetable oil polyol, wherein the pre-polymer is substantially free of any petrochemical polyol, compressing the foam pieces into a foam log of a desired density, and steaming the foam log to cure the pre-polymer. If desired, a process oil may be added to the pre-polymer to modify the viscosity of the pre-polymer.

A polyurethane foam created from a formulation comprising from about 1 percent to about 70 percent of a vegetable oil polyol is disclosed. The polyurethane foam is made from a formulation comprising an isocyanate, a surfactant, and a polyol blend comprising a vegetable oil polyol. Also disclosed is a polyurethane foam made from a formulation comprising a polyol blend comprising a petrochemical polyol and a vegetable oil polyol, and an isocyanate blend comprising a 2, 4 toluene diisocyanate (TDI) isomer and a 2, 6 TDI isomer, wherein the ratio of petrochemical polyol to vegetable oil polyol in the polyol blend is about equal to the ratio of the 2, 4 TDI isomer to the 2, 6 TDI isomer in the isocyanate blend.

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TITLE

Polyurethane Foam Product Manufactured With Vegetable Oil Polyol and Method for Manufacturing

TECHNICAL FIELD

[0004] The present disclosure relates generally to polyurethane foam and more specifically to polyurethane foam formulations containing vegetable oil polyol. The present disclosure further relates to methods for producing a prime foam from a component mixture formulated to include a vegetable oil polyol such as castor oil polyol. The present disclosure also relates generally to methods for making the bonded foam products, such as bonded foam flooring underlayment.

BACKGROUND

[0005] In its broadest sense, a floor is comprised of a subfloor over which a decorative covering is installed. Typically, the subfloor is either a slab of concrete or one or more sheets of plywood supported by a combination of joists, beams, posts and, in multiple-story buildings, bearing walls. The primary types of floor coverings used in structures are "soft" floor coverings and "hard" floor coverings. As its name suggests, soft floor coverings are soft, quiet underfoot, and tend to yield upon application of a force thereto. Hard floor coverings, on the other hand, are hard and rigid, but tend to be durable and easy to maintain.

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[0006] Generally, an underlayment is installed between the subfloor and the floor covering. The underlayment provides a cushion and decreases the wear of the floor covering. Underlayment also smoothes imperfections in the subfloor. Cushioning is important for both hard floor coverings and soft floor coverings, although the type of underlayment varies for each application. Hard floor coverings, such as wood, tend to have thinner, denser underlayments that absorb the sound of a person walking on the hard floor coverings. Soft floor coverings, such as carpet, tend to have thicker, less dense underlayment to enhance the softness of the soft flooring product, reduce wear, improve cleaning, and reduce high points or “peaks”, low points or “valleys”, and other irregularities in the subfloor. Underlayments may also provide a more level surface for floor coverings.

[0007] Underlayments are made out of various different types of materials. Some underlayments are made out of nonwoven fiber batts. Other underlayments are made out of foam coated onto a woven or nonwoven fabric scrim or substrate. Foam rubber or latex can also be used as underlayment. Additionally, underlayment can be composed of prime polyurethane foam, which is cut to various thicknesses from larger foam blocks. These prime polyurethane blocks do not incorporate the use of ground, recycled scrap polyurethane into the process, as in bonded foam. Prime foam is produced by mixing various chemical compounds together to create highly cross-linked polyurethane chains where density is primarily controlled by the amount of water in the formulation, and to a lesser extent, the degree of off-gassing resulting from the reaction of water and isocyanate, which influences the degree of cell expansion.

[0008] Perhaps the most common type of underlayment is bonded foam underlayment. Bonded foam underlayment is manufactured by shredding scrap foam into small pieces and then forming a larger piece of bonded foam from the shredded pieces of scrap foam. In one method, after the scrap foam is shredded, the foam pieces are coated with a pre-polymer comprised of isocyanate and polyol,

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and compressed into a foam log. Moisture, usually steam, is then added to the foam log to cure the pre-polymer, thereby binding the foam pieces together.

[0009] One of the ongoing concerns of many bonded foam underlayment manufacturers is the need to reduce manufacturing costs. Lowered manufacturing costs result in lower product costs, which make the bonded foam underlayment more appealing to the consumers. Bonded foam underlayment consumers, particularly large retail outlets and flooring installers, are constantly seeking the lowest price on flooring underlayment and frequently change suppliers in order to save a few cents per square foot of underlayment. Thus, it is in the manufacturers' best interest to produce flooring underlayment for the lowest possible price. As the cost of upgrading manufacturing equipment to improve efficiency can be prohibitive, most manufacturers seek to lower production costs by using less expensive materials to manufacture the underlayment.

[0010] Another ongoing concern regarding bonded foam operations is the byproducts produced when mixing and curing the pre-polymer. Traditional bonded foam pre-polymers and their chemical precursors generate numerous volatile organic compounds (VOCs) as a result of raw material chemical vapors or the reaction between the isocyanate and the polyol. VOC emissions are closely monitored and regulated by the Environmental Protection Agency (EPA) and other environmental groups and in many cases there are limits on the amount of VOCs that a manufacturing facility can emit. Thus, any process or product that reduces the VOC emissions is preferable because it is more environmentally friendly than the current bonded foam processes. In addition to the environmentally beneficial aspects, a sufficient reduction in VOCs allows manufacturers to market their products as "green", which is a product trait preferred by many consumers.

[0011] Consequently, there exists a need for a flooring underlayment that is less expensive to manufacture than existing flooring underlayments, which will allow manufacturers to produce and sell

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a flooring underlayment to consumers at a reduced cost. A need also exists for a method for reducing the VOC emissions associated with a bonded foam production process. A new method for manufacturing bonded foam product has now been found which employs vegetable oil polyol. The process and resulting product provide a lower cost, higher quality product and the manufacturing process reduces VOC emissions.

BRIEF SUMMARY OF THE DISCLOSURE

[0012] In one aspect, disclosed herein is a polyurethane foam created from a formulation comprised of between about 1 percent and about 70 percent of a vegetable oil polyol. In alternate embodiments thereof, the formulation further comprises between about 5 percent and about 25 percent of the vegetable oil polyol or between about 8 percent and about 12 percent of the vegetable oil polyol. In further alternate embodiments thereof, the vegetable oil polyol has a hydroxyl number between about 150 mg KOH/g and about 175 mg KOH/g or a hydroxyl number between about 50 mg KOH/g and about 60 mg KOH/g. In still further alternate embodiments thereof, the vegetable polyol has an acid value of not more than about 3 mg KOH/g or between about 4 mg KOH/g and about 9 mg KOH/g. In still yet further alternate embodiments thereof, the vegetable oil polyol is a castor oil polyol or a soy oil polyol.

[0013] In another aspect, disclosed herein is a polyurethane foam made from a formulation comprised of an isocyanate, a surfactant, and a polyol blend which includes a vegetable oil polyol. In one embodiment, the formulation comprises about 100 parts of the polyol blend; between about 40 parts and about 60 parts of the isocyanate; and between about 0.1 parts and about 3 parts of the surfactant. Variously, the vegetable oil polyol comprises between about 5 percent and about 95 percent of the polyol blend, between about 10 percent and about 50 percent of the polyol blend, or between about 15 percent and about 25 percent of the polyol blend.

In another aspect of this invention therein disclosed herein is a pre-polymer comprising between about 22 percent and about 32 percent of the isocyanate, between about 33 percent and about 43 percent of the vegetable oil polyol, and between about 30 percent and about 40 percent of the process oil.

In a further aspect, there is also provided a method wherein the pre-polymer comprises between about 22 percent and about 32 percent of the isocyanate, between about 33 percent and about 43 percent of the vegetable oil polyol, and between about 30 percent and about 40 percent of the process oil; and wherein the bonded foam product has a density of at least about 4 pcf. And more particularly within a method wherein the pre-polymer comprises between about 22 percent and about 32 percent of the isocyanate, between about 35 percent and about 45 percent of the vegetable oil polyol, and between about 28 percent and about 38 percent of the process oil; and wherein the bonded foam product has a density of less than about 4 pcf.

A further aspect of the invention relates to a bonded polyurethane foam made from a pre-polymer formulation which includes between about 5 percent and about 95 percent of a vegetable oil polyol, and a non-acidified isocyanate, and wherein the pre-polymer formulation is substantially free of petrochemical polyol.

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[0014] In still another aspect, disclosed herein is a polyurethane foam made from a formulation comprised of a polyol blend which includes a petrochemical polyol and a vegetable oil polyol; and an isocyanate blend which comprises a 2, 4 toluene diisocyanate (TDI) isomer and a 2, 6 TDI isomer. In further accordance with this aspect, the ratio of petrochemical polyol to vegetable oil polyol in the polyol blend is about equal to the ratio of the 2, 4 TDI isomer to the 2, 6 TDI isomer in the isocyanate blend. In one embodiment thereof, the petrochemical polyol is a polyether polyol. In another, the vegetable oil polyol is a castor oil polyol having a hydroxyl number from about 155 mg KOH/g to about 175 mg KOH/g and an acid value not more than about 3 mg KOH/g.

[0015] The foregoing has outlined rather broadly the features and technical advantages of the subject matter set forth herein in order that the detailed description which follows may be better understood.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] For a more complete understanding of the present invention, and for further details and advantages thereof, reference is now made to the accompanying drawings, in which:

[0017] FIG. 1 is a block diagram of one embodiment of a method for making the bonded foam product manufactured with vegetable oil polyol;

[0018] FIG. 2 is a side view of a coating machine suitable for implementing the method for making the bonded foam product manufactured with vegetable oil polyol of FIG. 1;

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[0019] FIG. 3 is a side view of a molding machine suitable for implementing the method for making the bonded foam product manufactured with vegetable oil polyol of FIG. 1;

[0020] FIG. 4 is a side view of a peeling machine suitable for implementing the method for making the bonded foam product manufactured with vegetable oil polyol of FIG. 1;

[0021] FIG. 5 is a side view of a continuous extruder suitable for implementing the method for making the bonded foam product manufactured with vegetable oil polyol of FIG. 1;

[0022] FIG. 6 is a perspective view of a bonded floor covering underlayment which may be made by the method for making the bonded foam product manufactured with vegetable oil polyol of FIG. 1;

[0023] FIG. 7 is a block diagram of one embodiment of a method for producing the foam; and

[0024] FIG. 8 is a side view of an example of an apparatus for implementing the method for producing the foam.

DETAILED DESCRIPTION

[0025] The bonded foam product manufactured with vegetable oil polyol will now be described in further detail. The bonded foam product manufactured with vegetable oil polyol is a bonded foam product, preferably flooring underlayment, manufactured using a pre-polymer formulation that utilizes a vegetable oil polyol in the pre-polymer. While a variety of vegetable oil polyols may be used in the pre-polymer formulation, the preferred vegetable oil polyol is castor oil polyol. Use of the vegetable oil polyol in the pre-polymer is environmentally friendly, less expensive, and produces a higher quality product as compared to use of a petrochemical polyol in the pre-polymer.

[0026] The term "polyol" is a generic name for polymers and oligomers containing a large number of hydroxyl (OH) groups. Two important characteristics of a polyol are its functionality and its hydroxyl number. The functionality is a measure of the ability of a polyol to form covalent bonds with another molecule or group in a chemical reaction, expressed in terms of the number of functional

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groups capable of participating in the reaction, such as 1, 2, or 3. When polyols are manufactured, the functionality of the polyol is controlled by the selection of the initiator. For example, a glycol initiator produces a diol, a glycerin initiator produces a triol, an ethylene diamine initiator produces a tetrol, and a sorbitol initiator produces a hexol. By contrast, the hydroxyl number is a measure of the quantity of hydroxyl groups present in an organic material, expressed in terms of milligrams of potassium hydroxide required to produce a hydroxyl content equivalent to the hydroxyl content of one gram of the organic material (mg KOH/g). When polyols are manufactured, the hydroxyl number is controlled by the selection of the organic acids used in the polymerization reaction.

[0027] A vegetable oil polyol substantially free of petrochemical polyols is employed to manufacture a pre-polymer formulation. As opposed to petrochemical polyols which are produced from crude oil and other petroleum sources, vegetable oil polyols are derived from plants and other natural sources. Vegetable oil polyols are primarily triglycerides of fatty acids, which are composed of a carboxyl group attached to a longer chain of hydrocarbons. The vegetable oil polyols can be saturated, that is they do not contain any carbon-carbon double bonds, or unsaturated such that they contain carbon-carbon double bonds. Each vegetable oil polyol has a different distribution and concentration of carbon-carbon double bonds and hydroxyl groups, which means that each vegetable oil polyol gives the pre-polymer different characteristics in reaction speed and completion, viscosity, and composition. These differences in derivation and chemical structure are what distinguish a vegetable oil polyol from a petrochemical polyol.

[0028] There are a variety of vegetable oil polyols suitable for use in the pre-polymer formulation of the invention. Suitable vegetable oil polyols may be produced from any naturally occurring vegetable oil, such as soy oil, castor oil, safflower oil, sesame oil, peanut oil, cottonseed oil, olive oil, linseed oil, palm oil, vegetable oil, canola oil, and blends thereof. Of course, a person of ordinary skill

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in the art will appreciate that the aforementioned list is not exhaustive and that other vegetable oils exist with the suitable characteristics exemplified above. While use of any vegetable oil polyol in the pre-polymer formulation produces the benefits described herein, some vegetable oils require chemical processing before they are suitable for use as a vegetable oil polyol. For example, crude soy oil consists of 17 percent saturated triglycerides and 83 percent unsaturated triglycerides, with about 4.41 double bonds per triglyceride molecule. To convert crude soy oil into soy oil polyol, the crude soy oil must be functionalized. Functionalization is a process by which hydroxyl groups are added to the unsaturated portions of the molecule. Functionalization can be accomplished through hydroxylation, the addition of hydroxyl groups to the molecule. In crude soy oil, the saturated portion of the triglyceride cannot be functionalized; thus 17 percent of the soy oil cannot be converted into a polyol. Consequently, in order to maximize the environmental and economic benefits of the vegetable oil polyol, the preferred vegetable oil polyols are made from vegetable oils which require minimal processing to become suitable for use as a vegetable oil polyol. Especially preferred are those vegetable oils that require minimal changes in their chemical structure in order to be suitable for use as a vegetable oil polyol.

[0029] There are several benefits to using vegetable oil polyol to manufacture the bonded foam pre-polymer. Bonded foam underlayment produced using the vegetable oil polyol pre-polymer has superior tensile strength and percent elongation values compared with bonded foam underlayment produced using petrochemical polyol pre-polymer. In addition, use of the vegetable oil polyol pre-polymer causes the bonded foam operations to produce less VOCs than are produced using the petrochemical polyol pre-polymer. Moreover, because vegetable oil polyols are produced from plants, they are a renewable raw material and are thus more environmentally friendly. Furthermore, because the vegetable oil polyol has a higher hydroxyl number than petrochemical polyols, less

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vegetable oil polyol is needed in the pre-polymer formulations to achieve the required excess free isocyanate percentage compared to petrochemical polyols, resulting in less polyol use and lower pre-polymer costs. The required free isocyanate content is also less with vegetable oil polyol, resulting in less polyol use and lower pre-polymer costs. For example, a free isocyanate content of about 8 percent to about 10 percent results in acceptable vegetable oil polyol pre-polymer versus the free isocyanate content of about 10 percent to about 12 percent that is required for petrochemical polyol pre-polymer.

[0030] Castor oil polyol is an example of a preferred polyol because the castor oil does not require excess processing steps to be suitable for use as a polyol. Unlike soy oil and other vegetable oils that require substantial processing to be suitable for use as a polyol, castor oil does not require any chemical processing steps, such as hydroxylation, esterification, etherification, and so forth, which would modify the castor oil's chemical structure to make it suitable for use as a polyol. Generally, the castor oil is cleaned and filtered to remove solids from the oil. The castor oil may also be dried to reduce the moisture content within the castor oil. The castor oil may optionally be polymerized to increase its molecular weight; however polymerization does not substantially change the chemical structure of the underlying castor oil molecules, it merely connects them together. Different grades of castor oils can be obtained through various refining process steps, which result in different functionalities, hydroxyl numbers, and molecular weights, but in the most preferred embodiment, the castor oil molecules are substantially unmodified.

[0031] Castor oil polyol is also the most preferred vegetable oil polyol because it has a combination of preferable chemical properties. Castor oil consists of about 90 percent ricinoleic acid, which is an 18 carbon acid having a double bond between the 9th and the 10th carbons and a hydroxyl group on the 12th carbon. The combination of unsaturated carbon bonds and a hydroxyl group is rare

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and only occurs in a few vegetable oils, one of which is castor oil. Castor oil polyol also has a relatively high hydroxyl number, generally in the range of about 150 to about 170, whereas petrochemical polyols have a lower hydroxyl number, generally in the range of 40 to 70. The higher hydroxyl number means that, compared to petrochemical polyols, less castor oil polyol is required to react with a given amount of isocyanate. The combination of chemical structure and high hydroxyl number makes the castor oil polyol more chemically efficient than the petrochemical polyol for use in pre-polymer for bonded foam operations.

[0032] In addition to its chemical properties, castor oil has various physical properties that make it the preferred vegetable oil polyol. For example, castor oil has a lower oxidation rate than many of the other vegetable oil polyols, including soy oil polyol. Thus, the castor oil polyol has a longer shelf life than many of the other vegetable oil polyols, including soy oil polyol. In addition, the castor oil polyol has a clear color, whereas soy oil and other vegetable oil polyols have a brown or yellow color. The clear color is preferred because it does not change the color of the bonded foam product, whereas the yellow or brown color in other vegetable oil polyols affects the color of the bonded foam product. Furthermore, castor oil has a lower viscosity than most of the other vegetable oil polyols, including soy oil polyol. Soy oil polyol, such as Biobased's Agrol 3.0, generally has a viscosity of at least about 3,500 centipoise (cp), which is substantially greater than the viscosity of castor oil polyol such as POLYOL 3000 available from Rutherford Chemicals LLC's CasChem Division, which has a viscosity of about 400 cp. As explained in detail below, process oil with a viscosity of about 30 to about 50 cp has to be added to the pre-polymer to reduce the viscosity to the preferred level of less than 1,000 cp. If the vegetable oil polyol has a higher viscosity, as is the case with soy oil polyol, additional process oil has to be added to the pre-polymer in order to reduce the viscosity, which increases the cost of the pre-polymer. Thus, less process oil has to be added to the pre-polymer when

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castor oil polyol is used as compared with other vegetable oil polyols, such as soy oil. The odor of castor oil polyol is not as strong as other vegetable oil polyols, including soy oil polyol, resulting in less of a retained odor in the bonded foam product.

[0033] FIG. 1 depicts a block diagram of the major steps comprising one embodiment of a method 10 for making the bonded foam product manufactured with vegetable oil polyol. The method 10 comprises: shredding foam into foam pieces 15, separately mixing a pre-polymer 20, coating the foam pieces with the pre-polymer 25, compressing the foam pieces into a foam log 30, steaming the foam log 35, drying the foam log 40, coring the foam log 45, and peeling the foam log 50 into sheets which may be used as flooring underlayment. Each of these steps is described in greater detail below.

[0034] The method 10 for making the bonded foam product manufactured with vegetable oil polyol begins with foam, typically, scrap foam trimmings. The method 10 may be performed by the manufacturer of bonded foam products using scrap foam trimmings provided by a third party, for example, prime foam manufacturer, or, in the alternative, may be part of a recycling program instituted by a prime foam manufacturer or other manufacturer of foam products. Furthermore, the foam may either be new foam or recycled foam previously employed in the formation of bonded foam. The size and shape of the foam is unimportant because, as previously set forth, the foam is shredded into a plurality of smaller foam pieces at 15 of the method 10. Variously, it is contemplated that the foam may be polyurethane, latex, polyvinyl chloride (PVC), or any other polymeric foam of any density. It should be clearly understood, however, that the foregoing list of suitable foams is purely exemplary and it is fully contemplated that there are any number of other types of foams and/or foam compositions suitable for the uses contemplated herein.

[0035] The foam does not have to have any specific formulation or consistency. The foam is generally free of moisture and may contain an incidental amount of impurities, such as felt, fabric,

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fibers, leather, hair, metal, wood, plastic, and so forth. Preferably, the foam is polyurethane foam with a density similar to the desired density of the subsequently produced bonded foam product. If desired, the foam may be sorted by type and/or density prior to shredding such that foam pieces of similar composition and density are used to make a single foam log. Using foam of similar composition and density to make a single foam log produces a more uniform density throughout the foam log, and thus throughout the subsequently produced bonded foam products, for example, a bonded foam underlayment for a floor covering.

[0036] Once the foam for the foam log has been selected, the foam is placed in a shredding machine for shredding 15 in accordance with the method 10. A shredding machine is a machine with a plurality of blades that cut the foam into smaller pieces of foam. The amount of time that the foam spends in the shredding machine determines the size of the shredded pieces of foam. The shredding machine may be operated periodically to provide discrete batches of shredded foam or continuously to provide a continuous supply of shredded foam. An example of a suitable shredding machine is the foam shredder manufactured by the Ormont Corporation. The foam pieces may be a geometric shape, such as round or cubic, but are generally an irregular shape due to the shredding process. The shape of the smaller foam pieces is generally unimportant because the foam will conform to the shape of the mold subsequently used by a molding machine employed to implement 30 of the method 10. The size of the foam pieces should be such that they are large enough to be easily handled by the various machines implementing the method 10, yet small enough such that there is not an abundance of empty space between the foam particles. Preferably, the foam pieces are from about ¼-inch to about ¾-inch in each of length, width, and height dimensions.

[0037] While the foam is being shredded by the shredding machine 15, a pre-polymer formed from a blend of plural chemical compounds is mixed 20 in a separate process. It is contemplated that

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15 and 20 may, as illustrated herein, be performed generally contemporaneously with one another. However, it is further contemplated that 15 and 20 may instead be performed at separate times. For example, the shredded foam may be stored until the pre-polymer is formed. The pre-polymer would then be used to coat all or part of the stored shredded foam. In the alternative, however, the pre-polymer may be stored, for example, in a holding tank, until a supply of foam is shredded. The pre-polymer may then be used to coat the newly shredded foam.

[0038] A first chemical compound used to form part of the pre-polymer is an isocyanate. The isocyanate reacts with the polyol (discussed below) and moisture in the steam (see 35 of method 10) to bind the pieces of foam together. The isocyanate used in the method 10 for making the bonded foam product manufactured with vegetable oil polyol may be any type of isocyanate, such as toluene diisocyanate (TDI), diisocyanatodiphenyl methane (MDI), or blends thereof. Examples of suitable isocyanates include: m-phenylene diisocyanate, p-phenylene diisocyanate, polymethylene polyphenylisocyanate, 2,4-toluene diisocyanate, 2,6-toluene diisocyanate, 4,4'- diisocyanatodiphenyl methane, dianisidine diisocyanate, bitolylene diisocyanate, naphthalene-1,4-diisocyanate, diphenylene-4,4'-diisocyanate, xylylene-1,4-diisocyanate, xylylene-1,2-diisocyanate, xylylene-1,3-diisocyanate, bis(4-isocyanatophenyl)-methane, bis(3-methyl-4-isocyanatophenyl)-methane, 4,4-diphenylpropane diisocyanate, isophorone diisocyanate, hexamethylene diisocyanate, methylene-bis-cyclohexylisocyanate, and mixtures thereof. Of course, it is fully contemplated that the method 10 for making the bonded foam product manufactured with vegetable oil polyol may include other isocyanates suitable for the uses contemplated herein. Accordingly, it should be clearly understood that the specific isocyanates disclosed herein are merely provided by way of example and that isocyanates other than those specifically disclosed herein may be suitable for the uses contemplated herein. The preferred isocyanates are Vornanate T-80 Type I TDI and/or PM 199 MDI, both of which

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are available from the Dow Corporation. The isocyanate comprises between about 5 percent, by weight, and about 95 percent, by weight, of the total weight of the pre-polymer mixture, preferably between about 17 percent, by weight, and about 37 percent, by weight, of the total weight of the pre-polymer mixture. Most preferably, the isocyanate comprises between about 22 percent, by weight, and about 32 percent, by weight, of the total weight of the pre-polymer mixture.

[0039] A second chemical compound used to form part of the pre-polymer is a vegetable oil polyol. The polyol used in the method 10 for making the bonded foam product manufactured with vegetable oil polyol may be any type of vegetable oil polyol, as defined above. The preferred vegetable oil polyol is POLYOL 3000 available from Rutherford Chemicals LLC's CasChem Division. As before, the foregoing vegetable oil polyols are identified for purely exemplary purposes and it is fully contemplated that the method 10 for making the bonded foam product manufactured with vegetable oil polyol may instead include other suitable vegetable oil polyols not specifically disclosed herein. Because of the advantageous properties of the vegetable oil polyol identified above, less vegetable oil polyol is required in the pre-polymer formulation compared with the prior art pre-polymer formulations that utilize petrochemical polyols. The vegetable oil polyol comprises between about 5 percent, by weight, and about 95 percent, by weight, of the total pre-polymer mixture, preferably between about 25 percent, by weight, and about 50 percent, by weight, of the total pre-polymer mixture. Most preferably, the vegetable oil polyol comprises between about 33 percent and about 43 percent, by weight, of the total pre-polymer mixture. By comparison, the prior art pre-polymer formulations typically employ greater than 50 percent petrochemical polyol in the pre-polymer formulation.

[0040] In an alternative embodiment, a third chemical compound may be used to form part of the pre-polymer, namely process oil. The process oil lowers the overall viscosity of the pre-polymer

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solution to facilitate better mixing and distribution of the various components of the pre-polymer. Generally, a viscosity of less than about 1,000 cp is preferred for the herein described bonded foam production operations. A viscosity below 1,000 cp also allows the pre-polymer to uniformly coat the foam pieces so that improved bonding occurs. Accordingly, acceptable process oils have a viscosity below 1,000 cp, preferably below 500 cp, and most preferably below 100 cp, measured at a temperature between 69 °F and about 90 °F. The process oil may be any aromatic or non-aromatic, natural or synthetic oil. Examples of suitable process oils include: naphthenic oil, mineral oil, oiticica oil, anthracene oil, synthetic oil, and mixtures thereof, provided such oils have an appropriate viscosity. Of course, the foregoing oils are identified for purely exemplary purposes and it is fully contemplated that the method 10 for making the bonded foam product manufactured with vegetable oil polyol may instead include other suitable oils not specifically disclosed herein. The preferred process oil is Sundex 840 process oil, a process oil available from the Sun Oil Corporation. The process oil comprises between about 5 percent, by weight, and about 95 percent, by weight, of the total weight of the pre-polymer mixture, preferably between about 25 percent, by weight, and about 45 percent, by weight, of the total weight of the pre-polymer mixture. Most preferably, the oil comprises between about 30 percent, by weight, and about 40 percent, by weight, of the total weight of the pre-polymer mixture. Thus, in the most preferred embodiment, the pre-polymer comprises between about 22 percent and about 32 percent of the isocyanate, between about 33 percent and about 43 percent of the vegetable oil polyol, and between about 30 percent and about 40 percent of the process oil for a bonded foam with a density greater than 4 pcf, preferably from about 4 pcf to about 8 pcf. For bonded foam products with a density of less than 4 pcf, such as a density of 3 pcf, the pre-polymer comprises between about 22 percent and about 32 percent of the isocyanate, between about

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35 percent and about 45 percent of the vegetable oil polyol, and between about 28 percent and about 38 percent of the process oil.

[0041] The pre-polymer may also contain one or more other additives which individually or collectively improve one or more characteristics of the bonded foam product. One example of an additive is a catalyst, which catalyzes the curing process for the pre-polymer. The catalyst may be any amine catalyst, such as a tertiary amine catalyst. Examples of suitable tertiary amine catalysts include: triethylenediamine, tetramethylethylenediamine, bis (2-dimethylaminoethyl) ether, triethylamine, tripropylamine, tributylamine, triamylamine, pyridine, quinoline, dimethylpiperazine, piperazine, N,N-dimethylcyclohexylamine, N-ethylmorpholine, 2-methylpiperazine, N,N-dimethylethanolamine, tetramethylpropanediamine, methyltriethylenediamine, 2,4,6-tri(dimethylaminomethyl)phenol, N,N',N''-tris(dimethylaminopropyl)-sym-hexahydrotriazine, 2-(2-dimethylaminoethoxy)ethanol, trimethylaminoethylethanolamine, dimorpholinodiethylether (DMDEE), N-methylimidazole, dimethylamino pyridine, dimethylethylethanolamine, and mixtures thereof. Of course, persons of ordinary skill in the art will appreciate that the foregoing tertiary amine catalysts are identified for purely exemplary purposes and it should be clearly understood that the method 10 for making the bonded foam product manufactured with vegetable oil polyol may include catalysts other than those specifically disclosed herein. Preferably, the catalyst is DMDEE, such as the JEFFCAT® DMDEE catalyst, available from the Huntsman Corporation. The catalyst comprises between about 0.01 percent, by weight, and about 10 percent, by weight, of the total pre-polymer mixture, preferably between about 0.5 percent, by weight, and about 5 percent, by weight, of the total pre-polymer mixture. Most preferably, the catalyst comprises between about 1 percent, by weight, and about 3 percent, by weight, of the total pre-polymer mixture. The addition of DMDEE catalyst to bonded foam underlayment is described in U.S. Patent Application 11/024,069, published June 29,

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2006 as US 2006/0141239 A1, entitled "Method for Making a Bonded Foam Product Suitable for Use as an Underlayment for Floor Coverings."

[0042] The pre-polymer may also contain other additives, such as flame retardants, antimicrobial chemical compounds, antioxidants, and/or dyes. Of the foregoing types of additives, odor absorbing agents, flame retardant chemical compounds, such as melamine, expandable graphite, or dibromoneopentyl glycol, improve the flame retardant properties of the bonded foam product. Antimicrobial additives, such as zinc pyrithione, improve the antimicrobial properties of the bonded foam product. The addition of an antimicrobial chemical compound to a bonded foam product is described in U.S. patent application 10/840,309 entitled "Anti-Microbial Carpet Pad and Method of Making" filed May 6, 2004, published March 31, 2005 as US 2005/006 9694 A1. Various antioxidants, which may or may not include butylated hydroxy toluene (BHT) as an ingredient, improve the resistance of the foam to oxidative-type reactions, such as scorch resulting from high exothermic temperatures. Dyes, such as blue, green, yellow, orange, red, purple, brown, black, white, or gray colored dyes, may be used to create certain color pigments within the bonded foam to distinguish certain bonded foam products from other bonded foam products. The aforementioned additives may alternatively or additionally be present in the scrap foam prior to the addition of the pre-polymer. Of course, it is fully contemplated that the method 10 for making the bonded foam product manufactured with vegetable oil polyol may include other additives for improving these or other characteristics of the bonded foam product and/or enhancing the performance of one or more of 15, 20, 25, 30, 35, 40, 45, and/or 50 of the method 10. Accordingly, it should be clearly understood that the additives disclosed herein are set forth purely by way of example and it is fully contemplated that the method 10 may also include any number of other additives not specifically recited herein.

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[0043] As previously set forth, the components which collectively form the pre-polymer are combined and mixed 20 in a mixer. It is contemplated that the mixer may either be a dynamic mixer or a static mixer. It is further contemplated that the mixer may either be a batch mixer or a continuous process mixer. Preferably, the mixer is configured to include a tank containing a motorized paddle-type mixing blade. However, it should be fully understood that other types of mixers are suitable for the uses contemplated in the method 10 for making the bonded foam product manufactured with vegetable oil polyol. Accordingly, the method 10 should not be limited to the specific types of mixers disclosed herein. The components which collectively form the pre-polymer may be combined generally simultaneously with one another. Preferably, the components which collectively form the pre-polymer may be added one at a time to the pre-polymer as it is being mixed, starting with the isocyanate, then the polyol, ending with the addition of the process oil. In an embodiment, the temperature of the pre-polymer mixture is maintained from about 90 °F to about 110 °F and mixed for about 10 hours. Preferably, the pre-polymer is mixed until there are about 8 to 10 percent free isocyanates available for reacting with the steam during the steaming process. The mixed pre-polymer has a viscosity less than about 1,000 centipoise, preferably between about 800 and about 100 centipoise, and most preferably between about 400 and about 600 centipoise. The pre-polymer viscosity is measured at a temperature between about 69 °F and about 95 °F. Additional process oil may be added to the mixer to modify the viscosity, if necessary. Although the time varies depending on the composition of the pre-polymer, the pre-polymer is mixed for at least about four hours prior to application of the pre-polymer to the foam pieces. Preferably, the isocyanate, the polyol, and the process oil are mixed together for at least about six hours, more preferably at least about 10 hours.

[0044] Of course, persons of ordinary skill in the art will appreciate that the vegetable oil polyol can be used as the sole viscosity modification fluid within the pre-polymer, provided that the viscosity

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of the vegetable oil polyol is less than the desired viscosity (e.g., less than about 1,000 cp) of the pre-polymer. In other words, if the viscosity of the vegetable oil polyol is sufficiently low, then the vegetable oil polyol can be used to modify the viscosity of the pre-polymer instead of the process oil. For example, the castor oil polyol described herein has a viscosity of 400 cp, so it would be suitable for use as a viscosity modification fluid because additional castor oil polyol can be added to the pre-polymer to bring the pre-polymer within the desired viscosity range when the pre-polymer has a viscosity outside the desired range. Conversely, the soy oil polyol described herein has a viscosity of 3,500 cp, and thus would not be suitable for lowering the viscosity of the pre-polymer to the desired viscosity. Persons of ordinary skill in the art will appreciate that the vegetable oil polyol is generally more expensive than the process oil, so the process oil is generally the preferred additive for modifying the viscosity of the pre-polymer.

[0045] After the pre-polymer components (isocyanate, polyol, process oil, and any additives) have been suitably mixed 20, the pre-polymer is coated onto the shredded foam pieces 25. The coating machine used to coat the shredded foam pieces may be a batch or a continuous coating machine and may be oriented horizontally, vertically, or at any angle. FIG. 2 is an illustration of a suitable coating machine 100. The coating machine 100 comprises a tank 102, one or more agitators 104, and a pre-polymer applicator 106. The size and shape of the tank 102 may be varied to suit the particular application. Similarly, the number and type of agitators 104 may be varied to suit the particular application. The process of coating the foam pieces 110 begins by placing the foam pieces 110 inside the tank 102. The pre-polymer applicator 106 sprays the pre-polymer 108 onto the foam pieces 110. While the pre-polymer applicator 106 is spraying the foam pieces 110, the agitator 104 rotates relative to the tank 102 and moves the foam pieces 110 around within the tank 102. As the foam pieces 110 move around in the tank 102, the foam pieces 110 are substantially coated with the

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pre-polymer 108. The time required to substantially coat the foam pieces 110 with the pre-polymer 108 varies depending on the volume and density of the foam pieces 110, the size of the tank 102, and the number and type of agitators 104, but is generally between about 0.5 minutes and about 15 minutes. Preferably, the coating process proceeds for between about 1 minute and about 10 minutes, most preferably between about 1.5 minutes and about 2.5 minutes. Although the pre-polymer 108 is sprayed onto the foam pieces 110 in the coating process illustrated in FIG. 2, the pre-polymer may be applied to the foam pieces by other methods, such as dipping or roller coating. Thus, it is fully contemplated that the method 10 for making the bonded foam product manufactured with vegetable oil polyol includes other types of coating processes and should not be limited to the particular coating process disclosed herein.

[0046] After the foam pieces have been coated with the pre-polymer 25, the method 10 proceeds to 30 where the foam pieces are transferred to a mold for compression thereof. FIG. 3 is an illustration of a typical mold 120 suitable for compressing the foam pieces. The mold 120 comprises a base 129, a generally cylindrical wall 124 detachably coupled to the base 129, a piston 122, a drive system (not shown in FIG. 3), and a steam injection system 127. Under the influence of a force exerted by the drive system, the piston 122 moves vertically with respect to the generally cylindrical wall 124 to a pre-selected position. Thus, the volume of the mold 120 defined by the piston 122, the generally cylindrical wall 124, and the base 129 is known. The piston 122 is configured to be removed from within the wall 124 and positioned away from the remainder of the mold 120 to facilitate easy loading of foam pieces into the cylindrical cavity defined by the base 129 and the generally cylindrical wall 124. Removal of the piston also facilitates the removal of a foam log after the steam process herein below described is complete by allowing the generally cylindrical wall 124 to be detached from the base 129.

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[0047] When forming a foam log 126, the foam pieces are weighed before being loaded into the mold 120. After the foam pieces are loaded into the mold 120, the piston 122 compresses the foam pieces into a foam log 126. The compression ensures complete contact between the foam pieces in the foam log 126. Because the volume within the mold 120 is known and the weight of the foam pieces can be varied, the density of the foam log 126 can be selected by compressing a variable amount of foam pieces to a specific volume. For example, if the mold volume is 25 cubic feet and the desired density of the foam log is 4 pounds per cubic foot (pcf), then 100 pounds of foam are loaded in the mold 120. The weight of the foam pieces can be varied by loaded more or less foam pieces in the mold 120. The weight of the foam pieces can also be varied by changing the blend of foam pieces. In other words, the foam pieces can contain a mixture of high density foam and low density foam and the ratio of high density foam to low density foam can be varied to yield the appropriate weight of foam pieces. As an alternative method of achieving a desired density, the volume of the mold 120 can be varied for a specified weight of foam pieces. Although a batch-type mold is illustrated in FIG. 3, the foam pieces may be compressed using other compression methods, such as the continuous extruder illustrated in FIG. 5. The compression ratio of the bonded foam product can be expressed as a ratio of the height of the uncompressed foam pieces to the height of the compressed foam pieces for a given cross-sectional area. During the continuous extrusion process, foam pieces (crumbs) are typically compressed at ratios of about 38:28 for 3 pcf foam, about 48:28 for 5.5 pcf foam, and about 52:28 for 8 pcf foam. While a specific compression process is described and illustrated with respect to FIG. 3, it should be clearly understood that the method 10 for making the bonded foam product manufactured with vegetable oil polyol encompasses other types of compression processes and should not be limited to the particular compression process disclosed herein.

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[0048] Once the foam pieces are compressed 30 into a foam log 126, the method 10 proceeds to 35 where the foam log 126 is steamed to cure the pre-polymer. As seen in Fig. 3, the steam injection system 127 is coupled to a steam supply (not shown) and is configured to inject steam 128 through the base 129, for example, using a pressurized flow of the steam 128. The steam 128 passes through the foam log 126 and any excess steam 128 exits through apertures 129 formed in the piston 122. An inconsequential amount of foam may pass through apertures 129 along with the excess steam 128. The moisture in the steam 128 cures the pre-polymer. The steam 128 may be any steam that is at least about 212°F and a sufficient pressure to permeate the foam log 126. Preferably, the temperature of the steam is between about 220°F and about the combustion temperature of the foam (about 1400°F). The pressure of the steam is preferably between about 10 pounds per square inch gauge (psi) and about 100 psi. Most preferably, the temperature of the steam is between about 246°F and about 256°F and the pressure of the steam is between about 13 psi and 15 psi for a batch operation and between about 30 psi and about 45 psi for a continuous operation. The steaming time is dependent on the steam pressure and the density of the foam log. For a 4 pcf foam log and using the most preferred steam, the steam time is between about 0.5 minutes and about 3 minutes, preferably about 1.0 minutes and about 1.5 minutes. For an 8 pcf foam log and using the most preferred steam, the steam time is between about 1.5 minutes and about 5 minutes, preferably about 2 minutes and about 3 minutes. Steam times for foam logs of other densities need not be reproduced herein as such steam times can be readily interpolated or extrapolated from the foregoing steam times and other steam data. While a specific steaming process is described and illustrated with respect to FIG. 3, it should be clearly understood that the method 10 for making the bonded foam product manufactured with vegetable oil polyol encompasses other types of steaming processes and should not be limited to the particular steaming process disclosed herein.

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[0049] After the steaming process 35 is completed, the method 10 proceeds to 40 where the foam log 126 is removed from the mold 120 and allowed to dry. Here, in order to facilitate the easy unloading of the foam log 126 after the steaming process is complete, it is contemplated that the generally cylindrical wall 124 of the mold 120 is detached from the base 129 after the piston 122 is removed from within the generally cylindrical wall 124 and positioned away from the remainder of the mold 120. The required drying time is dependent on the density of the foam log 126 and the amount of moisture present in the foam log 126. Lower density foam logs 126 may be sufficiently dry to allow immediate processing. However, the foam logs 126 are generally set aside to dry for 12 to 24 hours at ambient temperature and humidity so that foam logs 126 are sufficiently dry such that the moisture in the foam log 126 does not affect any of the processing equipment downstream from the steaming process of step 35. If desired, the drying of the foam log 126 may be sped up by forcing ambient, heated, and/or dried air over or through the foam log 126. While a specific drying process is described herein, it should be clearly understood that the method 10 for making the bonded foam product manufactured with vegetable oil polyol encompasses other drying processes and should not be limited to the particular drying processes disclosed herein.

[0050] After the drying process 40 is completed, the method 10 proceeds to 45 where the foam log 126 is cored by drilling an aperture through a center axis thereof. A rod is then inserted into the aperture, thereby enabling the foam log 126 to be handled without damaging the foam. The method 10 then proceeds to 50 where the foam log 126 is transported to a suitably configured peeling machine, such peeling machine 130 illustrated in FIG. 4, for commencement of a peeling process described below.

[0051] As may be seen in FIG. 4, the peeling machine 130 comprises a blade 136, a conveyor 132, and a take-up roll 134. The foam log 126 is rotated against the blade 136 such that the blade

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peels off a length of a bonded foam product 138 having a desired thickness, T_1 , and formed from the bonded foam of the foam log 126. The bonded foam product 138 peeled off of the foam log 126 is uniformly thick. As disclosed herein, the bonded foam is continuously peeled off of the foam log 126 at a constant speed. Likewise, the foam log 126 is continuously lowered with respect to the blade 136 at a constant speed. As a result, that the blade 136 constantly peels off a thickness T_1 of foam from the foam log 126. In other words, as the diameter of the foam log 126 is reduced, the foam log 126 is lowered so that the bonded foam product 138 has a uniform thickness.

[0052] It is contemplated that the bonded foam product 138 formed in the foregoing manner will have a variety of applications, a number of which are not specifically recited herein. One particularly desirable application is the employment of the bonded foam product 138 as a flooring underlayment. A variety of characteristics make the bonded foam product 138 well suited for use as a flooring underlayment, among them, the formation of the bonded foam product 138 in an “endless” length of uniform thickness suitable for rolling. As the length of bonded foam product 138 is transported towards the take-up roll 134 the bonded foam product 138 may also be trimmed to a uniform width, particularly if, after peeling, the bonded foam product 138 is wider than the width desired for the selected application. The bonded foam product 138 continues to travel along the conveyor 132 and is collected on the take-up roll 134, thereby forming roll 135 of the bonded foam product 138. When the roll 135 is of a desired diameter, the bonded foam product 138 is cut along its widthwise dimension to sever the roll 135 from the “endless” length of the bonded foam product 138 which continues to be peeled from the continuing being peeled from the foam log 126. The roll 135 is now ready for transport to distributors, wholesalers, retailers and the like. If desired, the bonded foam product 138 may be cut up into different lengths. For example, the bonded foam product 138 may be cut to a shorter length so that the roll 135 is lighter and easier to handle.

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[0053] As an alternative to the batch compressing and steaming process described above, the present invention may be utilized in a continuous compressing and molding process. FIG. 5 illustrates a continuous extruder 140 used for continuously compressing and steaming the foam pieces 110 into a continuous foam log 150. The continuous extruder 140 comprises an upper conveyor 144, a lower conveyor 142, and a steam injection system 146. The process of compressing and steaming the foam log 150 begins with the placement of foam pieces 110 onto the lower conveyor 142. Because the density of the foam log 150 produced by the continuous extruder 140 depends on the mass flow rate of the foam pieces 110 through the continuous extruder 140 as well as the volumetric flow rate of the foam log 150 exiting the extruder, the weight of the foam pieces 110 is typically measured prior to placing the foam pieces 110 onto the lower conveyor 142. As the foam pieces 110 travel through the continuous extruder 140, the foam pieces 110 are compressed by the upper conveyor 144. Because the upper conveyor 144 and the lower conveyor 142 travel in the same direction and the foam pieces 110 are continuously entering the continuous extruder 140, the foam pieces 110 are compressed by the downward traveling upper conveyor 144. The height of the upper conveyor 144 over the lower conveyor 142 is adjustable and the density of the foam log 150 can be adjusted by raising and lowering the upper conveyor 144 relative to the lower conveyor 142.

[0054] When the foam log is at a desired density, steam 148 is injected into the underside of the foam log 150 through perforations in the lower conveyor 142, with any excess steam passing through the perforations in the upper conveyor 144. The continuous extruder 140 is configured such that the residence time of the foam log 150 in the steaming area of the continuous extruder 140 is equal to the steaming time required in the batch process. The foam log produced by the continuous extruder 140 is generally rectangular in cross section and, as a result, is typically sliced into sheets rather than peeled in the manner described above.

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[0055] FIG. 6 illustrates the application of the roll 135 of the bonded foam product 138 as a flooring underlayment 161 to be installed between a subfloor 162 and a flooring product 160. Typically, the flooring underlayment 161 would be rolled onto the subfloor, cut to size and then covered with the flooring product 160. Of course, the foregoing process would typically include the steps of joining of adjoining sections of flooring underlayment, if necessary, and adhering of the flooring underlayment 161 to the subfloor 162 and/or the flooring 160. The foregoing steps have been omitted, however, purely for ease of description. The flooring underlayment 161 cushions the flooring product 160, smoothes out imperfections in the subfloor 162, reduces sound reflection between the flooring product 160 and the subfloor 162, and if the flooring underlayment 161 is configured with a moisture barrier as discussed below, the flooring underlayment 161 discourages the transmission of moisture between the subfloor 162 and the flooring product 160. The most common use for a flooring underlayment 161 formed from bonded foam is as a carpet pad. Thus it is within the scope of the invention that the flooring product 160 is carpet. However, it is fully contemplated that the flooring underlayment 161 can be used in conjunction with a variety of other flooring products 160. Examples of other flooring products 160 are: wood flooring, laminate flooring, tile flooring, tile adhered to laminate flooring, vinyl flooring, and linoleum flooring. The method 10 for making the bonded foam product manufactured with vegetable oil polyol includes use of the bonded foam product as an underlayment for other flooring products and should not be limited to the specific flooring products disclosed herein.

[0056] In an alternative embodiment, a layer of film (not shown) may be added to one or more surfaces of the flooring underlayment 161. The film is a thin layer of material that is adhered or otherwise laminated onto the flooring underlayment 161. The film is made of a material that is impervious to liquid moisture and moisture vapor. Alternatively, the film may be permeable with

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respect to moisture vapor, but impervious to liquid moisture. Such films are advantageous because they discourage the transmission of liquid moisture across the underlayment yet allow the underlayment to “breathe.” Further in the alternative, the film may contain one hydrophobic side and one hydrophilic side. Such films encourage the migration of moisture in one direction, but not the other direction. The film is typically a polymeric film, such as polyethylene or ethylene vinyl acetate (EVA) copolymer. An example of a suitable film is 150 gauge low density polyethylene film weighing 35 grams per square meter, available from numerous manufacturers including Dow[®] and DuPont[®]. Of course, a person of ordinary skill in the art will appreciate that a number of other films are commercially available, any one of which may be suitable for the flooring underlayment 161, and that the present invention should not be limited by the specific examples disclosed herein.

[0057] Also disclosed herein are foam products containing a vegetable oil polyol and methods of producing the same. In an embodiment, the foam product is a prime polyurethane foam. The foam may be produced by the reaction of an isocyanate, a polyol, water and additives as needed to impart desired properties. In further embodiments thereof, the vegetable oil polyol comprises castor oil polyol or soy oil polyol and the resultant foam has improved physical properties such as an improved color and/or odor when compared to an otherwise identical foam lacking the castor oil polyol or the soy oil polyol.

[0058] In one embodiment, the formulation includes the polyol. As used herein, the term polyol is intended to encompass any type of polyol, such as diol, triol, tetrol, polyol, or blends thereof and specifically includes both polyether and polyester polyols. The polyol is generally selected based on its hydroxyl number, molecular weight, and processing conditions as recommended by the manufacturer. Examples of suitable polyols include: ethylene glycol, propylene glycol, butylene glycol, hexanediol, octanediol, neopentyl glycol, 1,4-bishydroxymethyl cyclohexane, 2-methyl-1,3-

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propane diol, glycerin, trimethylolethane, hexanetriol, butanetriol, quinol, polyester, methyl glucoside, triethyleneglycol, tetraethylene glycol, polyethylene glycol, dipropylene glycol, polypropylene glycol, diethylene glycol, glycerol, pentaerythritol, trimethylolpropane, sorbitol, mannitol, dibutylene glycol, polybutylene glycol, alkylene glycol, oxyalkylene glycol, ethylene glycol, diethylene glycol, dipropylene glycol, triethylene glycol, tripropylene glycol, tetraethylene glycol, tetrapropylene glycol, trimethylene glycol, tetramethylene glycol, 1,4-cyclohexanedimethanol (1,4-bis-hydroxymethylcyclohexane), vegetable oil polyols, and mixtures thereof. Specific examples of suitable polyols are the VORANOL® line, including 3136, 3137A, and 4001, available from the Dow Chemical Corporation of Midland, Michigan, the ALCUPOL® line of polyols available from Repsol YPF of Madrid Spain, the LUPRANOL, PLURACOL, and LUPRAPHEN lines available from BASF Aktiengesellschaft of Ludwigshafen, Germany, and one or more of SP-168, SP-170, SP-238, and SP-2744 available from the Peterson Chemical Supply LLC of Strawberry Point, Iowa. Of course, the foregoing polyols are identified for purely exemplary purposes and it is fully contemplated that the formulation may include other suitable polyols not specifically disclosed herein. Although the amount of polyol included in the formulation may vary, generally the amount of polyol is fixed at one hundred parts such that the other formulation components can be measured relative to the polyol, e.g. in parts-per-hundred (pph).

[0059] In embodiments, the polyol comprises a vegetable oil polyol and may optionally be substantially free of petrochemical polyols. As opposed to petrochemical polyols that are produced from crude oil and other petroleum sources, vegetable oil polyols are derived from plants and other renewable natural sources. Vegetable oil polyols are primarily triglycerides of fatty acids, which are composed of a carboxyl group attached to a longer chain of hydrocarbons. The vegetable oil polyols can be saturated, that is they do not contain any carbon-carbon double bonds, or unsaturated such that

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they contain carbon-carbon double bonds. Each vegetable oil polyol has a different distribution and concentration of carbon-carbon double bonds and hydroxyl groups. As a result, each vegetable oil polyol gives the foam different characteristics with respect to reaction speed and completion, viscosity, and composition. It is these differences in derivation and chemical structure are what distinguish the vegetable oil polyol from the petrochemical polyol.

[0060] Examples of vegetable oil polyols suitable for the purposes contemplated herein include, without limitation, those vegetable oil polyols produced from any naturally occurring vegetable oil, such as soy oil, castor oil, safflower oil, sesame oil, peanut oil, cottonseed oil, olive oil, linseed oil, palm oil, canola oil, and blends thereof. Specific example of suitable soy oil polyols are AGROL, including AGROL 3.0, available from BioBased Technologies of Rogers, Arkansas, and SOYOL, including SOYOL R2-052, available from Urethane Soy Systems Company of Volga, South Dakota. SOYOL R2-052 is a two functional polyol made from unmodified soybean oil and having a hydroxyl number (ASTM D4274-99) between about 52 milligrams of potassium hydroxide per gram (mg KOH/g) and about 56 mg KOH/g and an acid value (ASTM D4662-03) between about 5.4 mg KOH/g and about 7.4 mg KOH/g. SOYOL R2-052 also has a moisture content (ASTM D4672-00) of no more than about 0.1 weight percent and a viscosity (ASTM D4878-03) between about 2500 centipoise (cp) and about 4,000 cp. Of course, a person of ordinary skill in the art will appreciate that the aforementioned list is not exhaustive and that other vegetable oils exist that are also suitable for the purposes contemplated herein.

[0061] The formulation may contain various amounts of the vegetable oil polyol. In alternate embodiments thereof, the formulation may comprise between about 5 parts and about 100 parts of the vegetable oil polyol, between about 10 parts and about 50 parts of the vegetable oil polyol, or between about 15 parts and about 25 parts of the vegetable oil polyol. In another embodiment, the formulation

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comprises about 100 parts of the vegetable oil polyol and all of the other formulation components are measured in pph based upon the vegetable oil polyol. In yet another embodiment, the polyol is a blend comprised of a vegetable oil and a petrochemical-based polyol. In such embodiments, the polyol blend may, in the alternative, be comprised of between about 5 percent and about 95 percent of the vegetable oil polyol with the remainder of the blend being the petrochemical polyol, t between about 10 percent and about 50 percent of the vegetable oil polyol with the remainder of the blend being the petrochemical polyol, or between about 15 percent and about 25 percent of the vegetable oil polyol with the remainder of the blend being the petrochemical polyol.

[0062] While use of any vegetable oil polyol in the formulation produces the benefits described herein, some vegetable oils require chemical processing before they are suitable for use as a vegetable oil polyol. For example, crude soy oil consists of about 17 percent saturated triglycerides and about 83 percent unsaturated triglycerides, with about 4.41 double bonds per triglyceride molecule. To convert crude soy oil into a preferred soy oil polyol, the crude soy oil may be functionalized. Functionalization is a process by which hydroxyl groups are added to the unsaturated portions of the molecule. Functionalization can be accomplished through hydroxylation, the addition of hydroxyl groups to the molecule. In some crude soy oils, the saturated portion of the triglyceride cannot be functionalized and, as a result, about 17 percent of the soy oil cannot be converted into a polyol. Consequently, in order to maximize the environmental and economic benefits of the vegetable oil polyol, the preferred vegetable oil polyols are made from vegetable oils that require minimal processing to become suitable for use as a vegetable oil polyol. Especially preferred are those vegetable oils that require minimal changes in their chemical structure in order to be suitable for use as the vegetable oil polyol.

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[0063] In that castor oil does not require excess processing steps to be suitable for use as a polyol, castor oil polyol is, under many circumstances, preferred over other types of vegetable oil polyols. Unlike other vegetable oils that require substantial processing to be suitable for use as the polyol, castor oil does not require any chemical processing steps, such as hydroxylation, esterification, etherification, and so forth, which would modify the chemical structure of the castor oil, thereby making it suitable for use as the polyol. Generally, the castor oil is cleaned and filtered to remove solids from the oil. The castor oil may also be dried to reduce the moisture content within the castor oil. Optionally, the castor oil may be polymerized to increase its molecular weight. In this regard, it should be noted, however, that polymerization merely connects the individual castor oil molecules together and does not substantially change the chemical structure of the underlying castor oil. It should be further noted that, while different grades of castor oils can be obtained through various refining process steps, thereby resulting in different functionalities, hydroxyl numbers, and molecular weights, it is generally preferred that the castor oil molecules remain substantially unmodified. Examples of castor oil polyols suitable for the purposes disclosed herein include CRYSTAL® 0, CRYSTAL® CROWN, POLYOL 3000 and POLYOL 3400, all of which are manufactured by the CasChem Division of Rutherford Chemicals LLC of Bayonne, New Jersey. Of the foregoing, POLYOL 3000 is clear to slightly hazy in color, has a Gardner color no more than about 3+, a hydroxyl value between about 160 mg KOH/g and about 168 mg KOH/g, an acid value of no more than about 2.5 mg KOH/g, a Karl Fischer moisture content of no more than about 0.35 percent, and a viscosity at 25°C of between about 68 centistokes (cs) and about 78 cs.

[0064] Castor oil polyol is often preferred over other vegetable oil polyols because it has a combination of desirable chemical properties. More specifically, castor oil consists of about 90 percent ricinoleic acid, an 18 carbon acid having a double bond between the 9th and 10th carbons and

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a hydroxyl group on the 12th carbon. This combination of unsaturated carbon bonds and a hydroxyl group is rare and only occurs in a few vegetable oils, one of which is castor oil. Castor oil polyol also has a relatively high hydroxyl number, typically in the range of about 150 to about 175. In contrast, chemical polyols have a substantially lower hydroxyl number, typically in the range of about 40 to about 70. Castor oil also generally has an acid value less than about 2.5 weight percent. Generally, the higher hydroxyl number and/or low acid number characterizing castor oil polyol, means that, compared to petrochemical polyols, less castor oil polyol is required to react with a given amount of isocyanate. Thus, the combination of chemical structure and high hydroxyl number makes castor oil polyol more chemically efficient than the petrochemical polyol for use in the formulations.

[0065] In addition to its chemical properties, castor oil is often preferred over other vegetable oils because of a number of physical properties. For example, castor oil has a lower oxidation rate than many of the other vegetable oil polyols. Thus, the castor oil polyol has a longer shelf life than many of the other vegetable oil polyols. In addition, the castor oil polyol has a clear color. This compares favorably to other vegetable oil polyols typically characterized by a brown or yellow color. The clear color is preferred because it does not change the color of the foam, whereas the yellow or brown color in other vegetable oil polyols affects the color of the foam.

[0066] Furthermore, castor oil polyol has a viscosity of about 400 cp. In contrast, other vegetable oil polyols tend to have a viscosity of at least 3,500 cp. As the viscosity of other vegetable oils is substantially higher than that of castor oil polyol, process oils having a viscosity of between about 30 and about 50 cp are often added to formulations which include high viscosity vegetable oil polyols, for example, those vegetable oil polyols having a viscosity of at least 3,500 cp, to reduce the viscosity to a more preferred level of less than about 1,000 cp. When process oils must be added to reduce the overall viscosity of the formulation, the cost of the formulation is increased. In contrast, lesser

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amounts of process oil are typically added to castor oil polyol. As a result, in contrast to formulations which include other vegetable oil polyols, the cost of formulations which include castor oil polyol are less likely to be adversely affected by the use of process oils. Finally, while the inclusion of any vegetable oil polyol in the foam reduces the odor of the foam, the odor of castor oil polyol is not as strong as other vegetable oil polyols resulting in less of a retained odor in the foam.

[0067] There are several benefits to using vegetable oil polyol to manufacture the foam. Use of the vegetable oil polyol causes the foam manufacturing process to produce less VOCs than are produced using the petrochemical polyol. Moreover, because vegetable oil polyols are produced from plants, they are a renewable raw material and are thus more environmentally friendly. Furthermore, because the vegetable oil polyol has a higher hydroxyl number than petrochemical polyols, less vegetable oil polyol is needed in the formulations to achieve the required excess free isocyanate percentage compared to petrochemical polyols, resulting in less polyol use and lower raw material costs. The required free isocyanate content is also less with vegetable oil polyol, resulting in less polyol use and lower costs. For example, a free isocyanate content of about 8 percent to about 10 percent results is acceptable for vegetable oil polyol versus the free isocyanate content of about 10 percent to about 12 percent that is required for petrochemical polyol.

[0068] In one embodiment, the formulation includes the isocyanate. The isocyanate reacts with the polyol to form the urethane chains, links, or struts within the foam and with the water to create gas within the foam. The isocyanate may be any type of isocyanate, such as toluene diisocyanate (TDI), diisocyanatodiphenyl methane (MDI), or blends thereof. One example of a suitable isocyanate is 80/20 TDI, which is a blend comprising 80 percent of the 2, 4 isomer of TDI and 20 percent of the 2, 6 isomer of TDI. Examples of other suitable isocyanates include: m-phenylene diisocyanate, p-phenylene diisocyanate, polymethylene polyphenyl-isocyanate, 2,4-toluene diisocyanate, 2,6-toluene

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diisocyanate, 4,4- diisocyanatodiphenyl methane, dianisidine diisocyanate, bitolylene diisocyanate, naphthalene-1,4-diisocyanate, diphenylene-4,4'-diisocyanate, xylylene-1,4-diisocyanate, xylylene-1,2-diisocyanate, xylylene-1,3-diisocyanate, bis(4-isocyanatophenyl)-methane, bis(3-methyl-4-isocyanatophenyl)-methane, 4,4-diphenylpropane diisocyanate, isophorone diisocyanate, hexamethylene diisocyanate, methylene-bis-cyclohexylisocyanate, and mixtures thereof. Examples of suitable isocyanates include, among others, SUPRASEC 7050 and SUPRASEC 304, both of which are available from Huntsman International LLC of Salt Lake City, Utah and VORANATE T-80 available from the Dow Chemical Corporation of Midland, Michigan. Of course, it should be clearly understood that the specific isocyanates disclosed herein are merely provided by way of example and that isocyanates other than those specifically disclosed herein may be suitable for use in the formulation. In embodiments, from about 10 pph to about 150 pph, from about 30 pph to about 70 pph, or from about 40 pph to about 60 pph isocyanates are present in the formulation. In one embodiment, it is advantageous to have a petrochemical polyol/vegetable oil polyol blend that has a similar blend ratio to the 2, 4 isomer TDI / 2, 6, isomer TDI blend. Thus, in one embodiment, the ratio of petrochemical polyol to vegetable oil polyol in the polyol blend is about equal to the ratio of the 2, 4 TDI isomer to the 2, 6 TDI isomer in the isocyanate blend.

[0069] One aspect of the formulation is an isocyanate index, which is one factor affecting the physical properties of the foam. The isocyanate index or merely "the index" is the stoichiometric amount of isocyanate needed to react with the active hydrogen components in the polyol. An index of 100 indicates that the formulation contains stoichiometrically equal amounts of isocyanate and active hydrogen components in the polyol. Indexes less than 100 indicate that the formulation contains an excess amount of polyol, whereas indexes above 100 indicate that the formulation contains an excess amount of isocyanate. Thus, an isocyanate index of 102 means that the formulation contains 102

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percent of the amount of isocyanate stoichiometrically required to react with all active hydrogen components in the polyol.

[0070] In one embodiment, the formulation includes a blowing agent. Water is an example of a suitable blowing agent; however the blowing reaction between isocyanate and water is exothermic and substantially increases the risk of the foam scorching, splitting, or igniting. Thus, inert blowing agents, such as CFCs or methylene chloride, have been employed to replace some of the water in the formulation. However, the use of CFCs and methylene chloride in the foam is generally discouraged because of the harmful effect these materials have on the environment. Consequently, in another embodiment, carbon dioxide is used as a blowing agent as a replacement for some or all of the CFCs, methylene chloride, and/or water. The carbon dioxide is typically mixed with the other formulation components at high pressure and low temperature such that the carbon dioxide remains in a liquid state. Carbon dioxide is advantageous because it not only expands thereby acting as a blowing agent to rise the foam, but also cools the foam as it expands, thereby reducing the overall foam temperature increase caused by the other exothermic chemical reactions within the foam. In embodiments, from about 0.01 pph to about 50 pph, from about 0.1 pph to about 20 pph, or from about 1 pph to about 5 pph of the blowing agent are present in the formulation.

[0071] In one embodiment, the formulation includes a catalyst. Catalysts are generally classified as either blowing catalysts or gelling catalysts, but some catalysts may act as both the blowing catalyst and the gelling catalyst. Blowing catalysts are generally tertiary amine catalysts and primarily catalyze the blowing reaction that creates porosity in the foam. Examples of suitable blowing catalysts include: trimethylamine, triethylenediamine, tetramethylethylenediamine, bis (2-dimethylaminoethyl) ether, triethylamine, tripropylamine, tributylamine, triamylamine, pyridine, quinoline, dimethylpiperazine, piperazine, N,N-dimethylcyclohexylamine, N-ethylmorpholine, 2-

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methylpiperazine, dimethylethanolamine, tetramethylpropanediamine, methyltriethylenediamine, 2,4,6-tri(dimethylaminomethyl)phenol, dimethylamino pyridine, dimethylaminoethanol, N,N',N''-tris(dimethylaminopropyl)-sym-hexahydrotriazine, 2-(2-dimethylaminoethoxy)ethanol, tetramethylpropanediamine, trimethylaminoethylethanolamine, dimorpholinodiethylether (DMDEE), N-methylimidazole, dimethylethylethanolamine, methyl triethylenediamine, N-methylmorpholine, and mixtures thereof. A specific example of a suitable blowing catalyst is the NIAX® line, including NIAX® A33, NIAX® A133, and NIAX® C-324, available from GE Advanced Materials of Pittsfield, Massachusetts, and the JEFFCAT® line of urethane catalysts, including JEFFCAT® ZF-10 and JEFFCAT® LS-15, both available from Huntsman International LLC of Salt Lake City, Utah.

[0072] Gelling catalysts are generally organo-tin catalysts and primarily catalyze the gelling reaction that creates the urethane chains, links, or struts within the foam. Examples of suitable gelling catalysts include: stannous or stannic compounds, stannous salts of carboxylic acids, stannous acylate, trialkyltin oxide, dialkyltin dihalide, dialkyltin oxide, dibutyltin dilaurate, dibutyltin diacetate, diethyltin diacetate, dihexyltin diacetate, di-2-ethylhexyltin oxide, dioctyltin dioxide, stannous octoate, stannous oleate, and mixtures thereof. Specific examples of suitable gelling catalysts include TCAT 110, TCAT 150, both of which are available from Gulbrandsen Manufacturing, Inc. of Orangeburg, South Carolina and Chemicals, K-19 and K-29, both of which are available from Goldschmidt Chemical Corp. of Hopewell, Virginia. Of course, persons of ordinary skill in the art will appreciate that the foregoing catalysts are identified for purely exemplary purposes and it should be clearly understood that the formulation may include catalysts other than those specifically disclosed herein. In various embodiments thereof, total catalyst levels present in the formulation may range between about 0.01 pph and about 10 pph, between about 0.05 pph and about 1 pph, or between about 0.2 pph and about 0.5 pph of the catalysts.

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[0073] In an embodiment, the formulation includes a surfactant. Surfactants are chemical compounds that affect the surface tension of liquids. Numerous types of surfactants are commercially available, including siloxane polyalkyleneoxide and octamethylcyclotetrasiloxane. An example of a suitable surfactant is the NIAX® silicone line of products, including NIAX® L-618, NIAX® L-635, and NIAX® L-650, all of which are available from GE Advanced Materials of Pittsfield, Massachusetts. Of course, it should be clearly understood that the specific surfactants disclosed herein are merely provided by way of example and that surfactants other than those specifically disclosed herein may be suitable for the uses contemplated herein as long as they affect the surface tension of the formulation. While the formulation may be substantially free of surfactants, in various embodiments thereof, the formulation for the foam may contain between about 0 pph and about 10 pph, between about 0.01 pph and about 5 pph, or between about 0.1 pph and about 2.5 pph of the surfactant. In other embodiments, the formulation for the foam contains no more than about 10 weight percent, between about 0.01 weight percent and about 2.5 weight percent, or between about 0.1 weight percent and about 0.5 weight percent of the surfactant.

[0074] In an embodiment, the formulation includes a foam processing aid. Foam processing aids are chemical compounds or chemical compound blends that improve the foaming properties of the foam. Generally, foam processing aids are blends of high hydroxyl number polyether or polyester polyols with other substances, such as dimethylcyclohexylamine and dipropylene glycol. Examples of suitable foam processing aids are the GEOLITE® modifier line, including GEOLITE® GM-206 and GEOLITE® GM-210, or the NIAX® modified line, including NIAX® DP-1022, all of which are available from GE Advanced Materials of Pittsfield, Massachusetts. Another suitable foam processing aid is SP-370 available from Peterson Chemical Supply LLC of Strawberry Point, Iowa. Of course, it should be clearly understood that the specific foam processing aids disclosed herein are

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merely provided by way of example and that foam processing aids other than those specifically disclosed herein may be suitable for the uses contemplated herein as long as they improve the foaming properties of the foam. In embodiments, the formulation for the foam contains between about 0 pph and about 10 pph, between about 0.01 pph and about 5 pph, or between about 0.1 pph and about 2.5 pph of the foam processing aid. In other embodiments, the formulation for the foam contains from about 0 weight percent to about 10 weight percent, from about 0.01 weight percent to about 2.5 weight percent, or from about 0.1 weight percent to about 0.5 weight percent of the foam processing aid.

[0075] The formulation may also include one or more other additives that individually or collectively improve one or more characteristics of the foam. These additives may include: flame retardants, antimicrobial chemical compounds, antioxidants, pigments, dyes, cross-linkers, stabilizers, and chain extenders. Of the foregoing types of additives, flame retardant chemical compounds, such as melamine, expandable graphite, or dibromoneopentyl glycol, improve the flame retardant properties of the foam product. Specific examples of suitable FR agents are FM-552 available from Great Lakes Chemical Corporation of West Lafayette, Indiana, HF-4 available from Supresta of Ardsley, New York or CP-2 available from Gulbrandsen Manufacturing, Inc. of Orangeburg, South Carolina. Antimicrobial chemical compounds, such as zinc pyrithione can be used to improve the antimicrobial properties of the foam. The addition of antimicrobial chemical compounds to foam is described in United States Patent Application 10/840,309 entitled "Anti-Microbial Carpet Pad and Method of Making" filed May 6, 2004 (published March 31, 2005 as US 2005/0069694 A1). Other antimicrobial chemical compounds, such *UltraFresh*® DM-50 available from Thompson Research Associates, Inc. of Toronto, Canada, have been used to improve the antimicrobial properties of the foam. In addition, various antioxidants and/or anti-scorch additives such as CS-15 available from GE

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Advanced Materials of Pittsfield, Massachusetts improve the resistance of the foam to oxidative-type reactions, such as scorch resulting from high exothermic temperatures. Dyes and/or pigmented colors, such as blue, green, yellow, orange, red, purple, brown, black, white, or gray, may be used to create certain colors within the foam based on customer requirements and to distinguish various grades of foam. Dyes such as X-3 (blue), X-15 (yellow), X-38 (orange), X-64 (red), and X-96 may also be used in the formulation. Other formulation additives such as such as foam stabilizers, cross-linkers, and chain extenders may also be included in the formulation as known to one of ordinary skill in the art. The aforementioned additives may alternatively or additionally be present in the formulation. Of course, it is fully contemplated that the formulation may include other additives for improving these or other characteristics of the foam.

[0076] The physical properties of the foam indicate whether the foam is a conventional, high resilience (HR), or viscoelastic foam. Conventional flexible slabstock polyurethane foam typically contains a majority of open cells and has greater air permeability characteristics than either HR or viscoelastic foam. In embodiments, the conventional polyurethane foam embodiment has a density from about 0.1 pounds per cubic foot (pcf) to about 10 pcf, from about 0.5 pcf to about 5 pcf, or from about 0.8 pcf to about 3.5 pcf. The firmness of the foam is measured by its indentation force deflection (IFD). Although the firmness of the foam is generally measured as the 25 percent IFD, the firmness may be measured in other IFD amounts, such as 65 percent IFD. In embodiments, the conventional polyurethane foam embodiment has an IFD from about 1 pound to about 200 pounds,

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from about 3 pounds to about 100 pounds, or from about 5 pounds to about 50 pounds. Moreover, the conventional polyurethane foam embodiment of the foam may have an index from about 60 to about 150, from about 80 to about 130, or from about 95 to about 120.

[0077] In contrast, HR foam is differentiated from conventional foam by its increased amount of closed cells within the foam, higher comfort or support factor, and higher resilience. In one embodiment, HR foam has a ball rebound value of greater than 60 percent. The lower resilience, conventional foam typically has a ball rebound value of less than about 55 percent and often below about 50 percent. In embodiments, the HR foam embodiment has a density from about 0.9 pcf to about 12 pcf, from about 1.4 pcf to about 7 pcf, or from about 1.8 pcf to about 3.5 pcf. In embodiments, the HR polyurethane foam embodiment has an IFD from about 5 pounds to about 70 pounds, from about 10 pounds to about 50 pounds, or from about 20 pounds to about 40 pounds. Furthermore, the HR polyurethane foam embodiment has an index from about 60 to about 150, from about 80 to about 130, or from about 100 to about 115.

[0078] Further in contrast, viscoelastic foam is differentiated from both conventional foam and HR foam in that it has both viscous and elastic properties. Viscoelastic foam is also called memory foam due to its relatively long recovery time after the removal of a compressive force. In embodiments, the viscoelastic polyurethane foam embodiment has a density from about 1 pcf to about 10 pcf, from about 2 pcf to about 6 pcf, or from about 3 pcf to about 5 pcf. In embodiments, the viscoelastic polyurethane foam embodiment of the foam has an IFD from about 1 pound to about 30 pounds, from about 3 pounds to about 20 pounds, or from about 5 pounds to about 13 pounds. In addition, the viscoelastic polyurethane foam embodiment of the foam has an index from about 20 to about 130, from about 50 to about 80, or from about 65 to about 75.

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[0079] Referring now to FIG. 1, a method for manufacturing a polyurethane foam from castor oil polyol or other vegetable oil polyol will now be described in greater detail. In a broad sense, the method disclosed herein produces the polyurethane foam by mixing a selected formulation which includes a vegetable oil polyol and subsequently producing, in accordance with any one of various means for producing a polyurethane foam known to one skilled in the art, a foam from the prepared formulation. FIG. 1 is a block diagram of one embodiment of a method 300 for producing the polyurethane foam. As may now be seen, the method 300 generally comprises: mixing the formulation components at 302, pouring the mixture into a trough at 304, allowing the reacting polymer to rise and form the foam at 306, cooling the foam at 308, curing the foam at 310, and processing the foam at 312. Each of the aforementioned steps is described in further detail below.

[0080] Production of the foam begins with mixing the components of the formulation together at 302. Generally, the formulation components are comprised of a vegetable oil polyol, a isocyanate, a blowing agent, a catalyst, and any additional components. The formulation components are typically stored in individual tanks or other suitable storage facilities and piped, pumped, metered, or otherwise transported to the mixer. The formulation components are then mixed together in the mixer, which may be a static mixer comprised of a plurality of baffles or a dynamic mixer comprised of a plurality of moving agitators. Of course, the mixing of formulation components should not be limited to the mixing methods described herein because persons of ordinary skill in the art are aware of other methods for mixing the formulation components described herein.

[0081] Production of the foam continues with the pouring of the formulation into the trough at 304. After all formulation components are mixed together, the reacting polymer is poured into a trough through a snorkel tube in the mix head or through a gate bar or letdown device, depending upon whether the process utilizes carbon dioxide or only water as a blowing agent. The gate bar or

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letdown device comprises a Cannon-Viking gatebar that is from about 1.8 to about 2 meters wide and is fitted with a shim to vary the slot exit velocity and pressure of the reacting foam as the pressure is decreased to atmospheric when the foam is released onto the fall plates. For carbon dioxide-blown foams, carbon dioxide is cooled and pressurized so that it remains dissolved in polyol once it is fed into the high-pressure polyol stream. Once the carbon dioxide/polyol solution and other formulation components exit the gatebar, the carbon dioxide expands and cools the foam as the pressure is released. Alternatively, most other formulation components are fed via positive displacement metering pumps into a manifold that feeds the high-speed mixer. Of course, the pouring of the formulation should not be limited to the foam pouring methods described herein because persons of ordinary skill in the art are aware of foam pouring techniques other than the methods specifically described herein.

[0082] Production of the foam continues with the rising of the foam on the fall plate at 306. After the polyurethane foam expands within the trough, it spills over the upper lip of the fall plate, also called a pour plate, and travels down the length of the fall plate. As the foam travels down the fall plate, the gelling and blowing reactions continue to occur within the foam such that the foam is simultaneously falling down the fall plate and rising due to the blowing reaction. The simultaneous rising and falling of the foam generally gives the top of the foam a level appearance from the trough to the end of the fall plate. In some embodiments, the foam may appear to have an inclination either towards the trough or away from the trough due to an imbalance between the change in thickness of the foam and the change in height of the fall plate. After the polyurethane foam travels the length of the fall plate, the foam passes onto a moving conveyor where it is transported down the production line. When the foam reaches a predetermined length, such as sixty feet, the foam is cut using a knife, hot wire, saw, or some other cutting apparatus, thereby separating it into separate bun lengths as it

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travels down the moving conveyor. Of course, the rising of the foam should not be limited to the foam rising methods described herein because persons of ordinary skill in the art are aware of foam rising methods other than the methods described herein.

[0083] Production of the foam continues with the cooling of the foam at 308. After the foam is cut, it is transported to the vacuum table. At this point the temperature of the foam is typically between about 200°F and about 350°F, and, even more typically, between about 250°F and about 325°F. Skin is formed on the surfaces of the foam. Therefore, it is desirable to remove these skin surfaces to allow air to pass through the foam to allow cooling during vacuum force curing. When the foam is positioned over the vacuum table, a vacuum source is applied to the bottom of the foam such that air is sucked into the top and sides of the foam and out of the bottom of the foam. The flow of air through the foam causes any VOCs within the foam to exit the foam via the vacuum source. The VOCs that are removed from the foam are subsequently filtered out of the exhaust stream using a pre-filter and a scrubber as described in further detail below. The foam remains on the vacuum table until the foam is cooled to a temperature between about 100°F and about 160°F. The foam then is transported to a curing, or bun storage area. When producing embodiments of the foam that have low or poor airflow characteristics, such as viscoelastic foam or closed cell HR foam, it is sometimes advantageous not to cool the foam using the vacuum table described herein. Not using the vacuum table may be advantageous because viscoelastic and HR foams possess such low airflow properties that the foam may become permanently flattened during the cooling process, and/or do not require forced air cooling due to the formulation being a low exothermic formulation with no risk of spontaneous combustion due to excessive exothermic cure temperatures. Thus, foams with low or poor airflow characteristics, and/or those that are not at risk of high exothermic temperature may not require forced vacuum cure system using ambient air. Of course, cooling of the foam should not be

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limited to the foam cooling methods described herein because persons of ordinary skill in the art are aware of foam cooling methods other than the methods described herein.

[0084] Production of the foam continues with the curing of the foam at 310. Generally, the foam is allowed to complete most of the reaction requiring at least about 30 minutes prior to vacuum. Higher exothermic formulations require specific cure times before vacuum to prevent the possibility of generating dangerous exothermic temperatures. After vacuum, foam is generally allowed to further cure an additional amount of time, such as between about 24 to about 48 hours. In some embodiments, those formulations that do generate high exothermic reaction temperatures, the curing process merely involves allowing the foam to cool to ambient temperature without vacuuming. In an embodiment, the cure times for these foams range from about 48 to about 72 hours to complete any remaining reactions and to cool the foam to ambient temperature. Of course, curing of the foam should not be limited to the foam curing methods described herein because persons of ordinary skill in the art are aware of foam curing methods other than the methods described herein.

[0085] Production of the foam continues with an optional processing of the foam at 312. The foam may be processed into a variety of foam products or merely sold as a bun. In one embodiment, the foam is sliced into layers of a predetermined thickness, such a one-half inch, one inch, or two inches. Such thicknesses of the foam are useful for a variety of purposes, including flooring underlayment, mattress components, furniture components, insulating materials, and the like. In alternative embodiments, specific shapes may be cut out of either the foam or the sliced layers of the foam. The specific shapes may be cut out of the foam using a die or other cutting devices. In one embodiment, a laser can be used to form specific complex shapes out of the foam. In further alternative embodiments, the foam or a sliced layer of the foam can be cut into a convoluted or other complex shape using a convoluting machine. Of course, processing of the foam should not be limited

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to the foam processing methods described herein because persons of ordinary skill in the art are aware of foam processing methods other than the methods described herein.

[0086] FIG. 2 is a side view of an example of foam production line 400 for implementing method 300. The foam production line 400 comprises a plurality of storage tanks 402, the mixer 404, the trough 406, the fall plate 408, the conveyor 410, the knife 412, the vacuum table 414, exhaust piping 416, the pre-filter 418, the scrubber 420, a vacuum pump 422, and vent piping 424. Production of the foam 230 begins when the formulation components described hereinabove flow from the storage tanks 402 to the mixer 404. Although only three storage tanks 402 are depicted in FIG. 2, the foam production line 400 may be configured with any number of storage tanks 402 and generally includes one storage tank 402 for each formulation component. If desired, one or more pumps may be installed in the piping between the storage tanks 402 and the mixer 404 to facilitate transportation of the formulation components to the mixer 404. The mixer 404 then mixes the formulation components together. The mixer 404 may be a static mixer comprised of a plurality of baffles within the pipes or a dynamic mixer comprised of a plurality of moving agitators. After being mixed, the formulation is poured into the trough 406. If desired, one or more pumps may be installed in the piping between the mixer 404 and the trough 406 to facilitate transportation of the formulation to the trough 406. Alternatively, the formulation may gravity feed into the trough 406.

[0087] Once the formulation arrives in the trough 406, the gelling and blowing reactions begin to form the foam. The foam rises out of the trough 406, spills over onto the fall plate 408, and continues to rise as it progresses down the fall plate 408. The foam 230 eventually reaches the conveyor 410 and travels along the conveyor until the knife 412 is used to cut the foam 230 when it reaches a predetermined length, such as sixty feet. The foam 230 then moves along the conveyor 410 to the vacuum table 414 where ambient air is used to cool the foam 230. More specifically, the vacuum

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pump 422 draws air through the foam 230, into the vacuum table 414 as indicated by the arrows, and through the exhaust piping 416, the pre-filter 418, and the scrubber 420. The air then passes through the vacuum pump 422 and out the vent piping 424 where it is vented to the atmosphere. After being cooled, the foam 230 is transported, for example by crane, to an area for curing and further processing (not shown). A fume hood (not shown) is installed over the trough 406, the fall plate 408, and the conveyor 410 such that any vapors or fumes released from the foam 230 during its production are captured within the fume hood. The fumes and vapors captured in the fume hood are combined with the exhaust stream in the exhaust piping 416 and routed through the pre-filter 418 and the scrubber 420, before being vented to the atmosphere.

[0088] The scrubber 420 and the pre-filter 418 shown in FIG. 2 remove the VOCs from the exhaust stream so that the VOCs are not vented to the atmosphere. Several environmental agencies monitor the amount of VOCs that foam production facilities emit into the atmosphere, thus foam production facilities have to install scrubbers 420 to remove the VOCs from the exhaust stream before it is vented to the atmosphere. As the ambient air passes through the interior of the foam 230 and into the vacuum table 414, the air removes and carries with it the VOCs in the foam 230, including unused reactants from the gelling and/or blowing reactions, carbon dioxide, stabilizers, antioxidants, inert blowing agents, fluorocarbons, chlorofluorocarbons (CFCs), methylene chloride, acetone, trichloroethane, butylated hydroxytoluene (BHT), trace impurities from the raw materials, and other byproducts. Moreover, the exhaust stream can also include solid particulate matter drawn from the freshly produced foam and small pieces of foam that are vacuumed off of the foam 230. Although not harmful to the environment, the small pieces of foam are a nuisance and maintenance problem if discharged into the atmosphere. Thus, the solid portions of the exhaust stream are generally removed in the pre-filter 418, which comprises open cell polyurethane foam. Effective filtering of foam debris

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can also be accomplished using a woven or nonwoven fiber batt, a metal mesh, fiberglass, or other porous filter that will produce a minimum back pressure, or pressure drop across the pre-filter 418. The remaining undesirable substances in the exhaust stream, including the VOCs, are removed using the scrubber 420. The scrubber 420 comprises a bed of specialized activated carbon char that is specifically designed to adsorb the VOCs in the exhaust stream.

[0089] In an embodiment, the foam comprising vegetable oil polyol may display a variety of desirable characteristics such as an improved physical properties, color, and/or odor when compared to otherwise identical foam lacking the vegetable oil polyol.

EXAMPLE ONE

[0090] An experiment was conducted comparing the pre-polymer utilizing a soy oil polyol with the pre-polymer utilizing a petrochemical polyol for both TDI and MDI based pre-polymers. For this experiment, relatively small batches of pre-polymer were prepared using the two polyols and the two isocyanates. The soy oil polyol was Bio Based Agrol 3.0, a soy oil polyol with a functionality of 3.0, a hydroxyl number of 155 mg KOH/g, and a molecular weight of 1,100 g/mol. The soy oil polyol had a garner color of about 2+, an acid value of about 1.2, and about 0.16 percent moisture. The petrochemical polyol was Dow 3512, a polyether based polyol with a functionality of 3.0, a hydroxyl number of 48 mg KOH/g, and a molecular weight of 3,500 g/mol. The TDI was Dow Vornanate T-80 Type I TDI with 48.3 percent free isocyanates. The MDI was Dow PM 199 MDI with 31.9 percent free isocyanates. The isocyanates and polyol were mixed with Sundex 840 process oil, an aromatic process oil available from the Sun Oil Corporation. The results of the comparison are shown below in Tables 1 and 2.

TDI Based Pre-polymer						
	Soy Pre-polymer	Std. Pre-polymer	Soy Pre-polymer	Std. Pre-polymer	Soy Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
Type I TDI Dow Vornanate T-80	23	25	48.3	48.3		
BioBased Soy Polyol	12				155	

Dow Voranate T-80 Type 1 is a non-acidified isocyanate which can also be described as a low acidity grade isocyanate having an acidity maximum of 0.00040 wt% HCl.

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Dow 3512 Polyol		60				56
Sundex 840 Process Oil	65	15			0	0
Totals:	100	100	9.7	9.6		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:		1:10				
Steam time:		1.5 mins				
Drying time:		48 hours				
Density:		6.6 pcf				
Laboratory Viscosities						
		BioBased Soy Polyol		Dow Polyol 3512		
@ 69 Deg. F. (Initial Pre-polymer Mix):		70 cp		750 cp		

Table 1: Comparison of a pre-polymer utilizing TDI and a soy oil polyol with a pre-polymer utilizing TDI and a petrochemical polyol

MDI Based Pre-polymer						
	Soy Pre-polymer	Std. Pre-polymer	Soy Pre-polymer	Std. Pre-polymer	Soy Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
MDI DOW PM 199	33	33.3	31.9	31.9		
BioBased Soy Polyol	10				155	
Dow 3512 Polyol		33.4				56
Sundex 840 Process Oil	57	33.3			0	0
Totals:	100	100	9.7	9.6		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:		1:10				
Steam time:		1.5 mins				
Drying time:		48 hours				
Density:		6.6 pcf				
Laboratory Viscosities						
		BioBased Soy Polyol		Dow Polyol 3512		
@ 72 Deg. F. (Initial Pre-polymer Mix):		205 cp		1,100 cp		

Table 2: Comparison of a pre-polymer utilizing MDI and a soy oil polyol with a pre-polymer utilizing MDI and a petrochemical polyol

[0091] The experiment showed that vegetable oil polyol was less expensive than petrochemical polyol, but that the quality of the pre-polymer was better using vegetable oil polyol. Thus, the utilization of vegetable oil polyol in TDI and MDI based pre-polymers for bonded foam products represents an economically viable option.

EXAMPLE TWO

[0092] A second, larger scale experiment was conducted comparing the pre-polymers utilizing various different types and blends of vegetable oil polyols. Specifically, the pre-polymer contained TDI and one of the following polyols: soy oil polyol, castor oil polyol, a blend of soy oil polyol and

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petrochemical polyol, and a blend of castor oil polyol with petrochemical polyol. The viscosities of the samples at various temperatures and times were also measured. As with Example One above, the TDI was Dow Vornanate T-80 Type I TDI, the soy oil polyol was Agrol 3.0, and the petrochemical polyol was Dow 3512, the characteristics of which are described above. The castor oil polyol was CasChem #1 imported castor oil polyol, with a functionality of 2.7, a hydroxyl number of 164 mg KOH/g, and a molecular weight of 928 g/mol. The specific formulation for the pre-polymer with soy oil polyol was 162 pounds of TDI, 168 pounds of soy oil polyol, and 270 pounds of process oil, for a total of 600 pounds. The specific formulation for the pre-polymer with soy oil polyol / petrochemical polyol blend was 150 pounds of TDI, 180 pounds of 50:50 blended soy oil polyol and petrochemical polyol, and 270 pounds of process oil, for a total of 600 pounds. The specific formulation for the pre-polymer with castor oil polyol was 162 pounds of TDI, 162 pounds of castor oil polyol, and 276 pounds of process oil, for a total of 600 pounds. The specific formulation for the pre-polymer with castor oil polyol / petrochemical polyol blend was 150 pounds of TDI, 174 pounds of 50:50 blended castor oil polyol and petrochemical polyol, and 276 pounds of process oil, for a total of 600 pounds. The results of the comparison are shown below in Tables 3 through 6 below.

Soy Pre-polymer						
	Soy Pre-polymer	Std. Pre-polymer	Soy Pre-polymer	Std. Pre-polymer	Soy Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
Type I TDI Dow Vornanate T-80	27	25	48.3	48.3		
BioBased Soy Polyol	28				155	
Dow 3512 Polyol		60				49
Sundex 840 Process Oil	45	15			0	0
Totals:	100	100	9.8	9.9		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:		1.1:10.0				
Steam time:		1.5 mins				
Drying time:		48 hours				
Density:		6.6 pcf				
Laboratory Viscosities						
			BioBased Soy Polyol		Dow Polyol 3512	
@ 77 Deg. F. (Unmixed):			3570 cp		555 cp	
@ 69 Deg. F. (Initial Pre-polymer Mix):			70 cp		750 cp	
@ 75 Deg. F. (Initial Pre-polymer Mix):			50 cp		400 cp	

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@ 90 Deg. F. Final Pre-polymer Mix (After 6 hours):	200 cp	1,100 cp
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Table 3: Comparison of a pre-polymer utilizing TDI and a soy oil polyol with a pre-polymer utilizing TDI and a petrochemical polyol

50 % Soy Pre-polymer						
	50% Soy Pre-polymer	Std. Pre-polymer	50% Soy Pre-polymer	Std. Pre-polymer	50% Soy Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
Type I TDI Dow Vornanate T-80	25	25	48.3	48.3		
BioBased Soy Polyol	30				102	
Dow 3512 Polyol		60				49
Sundex 840 Process Oil	45	15			0	0
Totals:	100	100	9.8	9.6		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:	1.1:10.0					
Steam time:	1.5 mins					
Drying time:	48 hours					
Density:	6.6 pcf					
Laboratory Viscosities						
	50% BioBased Soy Polyol			Dow Polyol 3512		
@ 77 Deg. F. (Unmixed):	3570 cp			555 cp		

Table 4: Comparison of a pre-polymer utilizing TDI and a soy oil polyol / petrochemical polyol blend with a pre-polymer utilizing TDI and a petrochemical polyol

Castor Pre-polymer						
	Castor Pre-polymer	Std. Pre-polymer	Castor Pre-polymer	Std. Pre-polymer	Castor Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
Type I TDI Dow Vornanate T-80	27	25	48.3	48.3		
Castor Oil Polyol	27				164	
Dow 3512 Polyol		60				49
Sundex 840 Process Oil	46	15			0	0
Totals:	100	100	9.8	9.9		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:	1.1:10.0					
Steam time:	1.5 mins					
Drying time:	48 hours					
Density:	6.6 pcf					
Laboratory Viscosities						
	Castor Oil Polyol			Dow Polyol 3512		
@ 77 Deg. F. (Unmixed):				555 cp		
@ 69 Deg. F. (Initial Pre-polymer Mix):				750 cp		

Table 5: Comparison of a pre-polymer utilizing TDI and a castor oil polyol with a pre-polymer utilizing TDI and a petrochemical polyol

50 % Castor Pre-polymer						
	50% Castor Pre-polymer	Std. Pre-polymer	50% Castor Pre-polymer	Std. Pre-polymer	50% Castor Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #

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Type I TDI Dow Vornanate T-80	25	25	48.3	48.3		
Castor Oil Polyol	29				106.5	
Dow 3512 Polyol		60				49
Sundex 840 Process Oil	46	15			0	0
Totals:	100	100	9.8	9.9		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:	1.1:10.0					
Steam time:	1.5 mins					
Drying time:	48 hours					
Density:	6.6 pcf					
Laboratory Viscosities						
	50% Castor Oil Polyol			Dow Polyol 3512		
@ 77 Deg. F. (Unmixed):	3570 cp			555 cp		
@ 69 Deg. F. (Initial Pre-polymer Mix):				750 cp		
@ 75 Deg. F. (Initial Pre-polymer Mix):				400 cp		
@ 90 Deg. F. Final Pre-polymer Mix (After 6 hours):				1,100 cp		

Table 6: Comparison of a pre-polymer utilizing TDI and a castor oil polyol / petrochemical polyol blend with a pre-polymer utilizing TDI and a petrochemical polyol

[0093] As before, the experiment showed that vegetable oil polyol was less expensive than petrochemical polyol, but that the quality of the pre-polymer was better using vegetable oil polyol. Thus, the utilization of vegetable oil polyol in TDI based pre-polymers for bonded foam products represents an economically viable option.

EXAMPLE THREE

[0094] A third experiment was conducted in an effort to optimize the pre-polymer formulations. As with Example Two, the experiment compared the pre-polymers utilizing TDI and one of the following polyols: soy oil polyol, castor oil polyol, a blend of soy oil polyol and petrochemical polyol, and a blend of castor oil polyol with petrochemical polyol. The viscosities of the four samples at various temperatures and times were also measured. As with the preceding examples, the TDI was Dow Vornanate T-80 Type I TDI, the soy oil polyol was Agrol 3.0, the castor oil polyol was CasChem #1 Imported, and the petrochemical polyol was Dow 3512, the characteristics of which are described above. The specific formulation for the pre-polymer with soy oil polyol was 162 pounds of TDI, 168 pounds of soy oil polyol, and 270 pounds of process oil, for a total of 600 pounds. The specific formulation for the pre-polymer with soy oil polyol / petrochemical polyol blend was 150

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pounds of TDI, 180 pounds of 50:50 blended soy oil polyol and petrochemical polyol, and 270 pounds of process oil, for a total of 600 pounds. The specific formulation for the pre-polymer with castor oil polyol was 162 pounds of TDI, 258 pounds of castor oil polyol, and 180 pounds of process oil, for a total of 600 pounds. The specific formulation for the pre-polymer with castor oil polyol / petrochemical polyol blend was 150 pounds of TDI, 150 pounds of castor oil polyol, 150 pounds of petrochemical polyol, and 150 pounds of process oil, for a total of 600 pounds. The results of the comparison are shown below in Tables 7 through 10 below.

Soy Pre-polymer						
	Soy Pre-polymer	Std. Pre-polymer	Soy Pre-polymer	Std. Pre-polymer	Soy Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
Type I TDI Dow Vornanate T-80	27	25	48.3	48.3		
BioBased Soy Polyol	28				155	
Dow 3512 Polyol		50				49
Sundex 840 Process Oil	45	25			0	0
Totals:	100	100	9.8	10.2		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:	1.1:10.0					
Steam time:	1.5 mins					
Drying time:	48 hours					
Density:	6.6 pcf					
Laboratory Viscosities						
	BioBased Soy Polyol			Dow Polyol 3512		
@ 77 Deg. F. (Unmixed):	3570 cp			555 cp		
@ 69 Deg. F. (Initial Pre-polymer Mix):	70 cp			750 cp		
@ 75 Deg. F. (Initial Pre-polymer Mix):	50 cp			400 cp		
@ 90 Deg. F. Final Pre-polymer Mix (After 6 hours):	200 cp			1,100 cp		

Table 7: Comparison of a pre-polymer utilizing TDI and a soy oil polyol with a pre-polymer utilizing TDI and a petrochemical polyol

50 % Soy Pre-polymer						
	50% Soy Pre-polymer	Std. Pre-polymer	50% Soy Pre-polymer	Std. Pre-polymer	50% Soy Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
Type I TDI Dow Vornanate T-80	27	25	48.3	48.3		
BioBased Soy Polyol	28				102	
Dow 3512 Polyol		50				49
Sundex 840 Process Oil	45	25			0	0
Totals:	100	100	9.8	10.2		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:	1.1:10.0					
Steam time:	1.5 mins					
Drying time:	48 hours					

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Density:	6.6 pcf	
Laboratory Viscosities		
	50% BioBased Soy Polyol	Dow Polyol 3512
@ 77 Deg. F. (Unmixed):	3570 cp	555 cp

Table 8: Comparison of a pre-polymer utilizing TDI and a soy oil polyol / petrochemical polyol blend with a pre-polymer utilizing TDI and a petrochemical polyol

Castor Pre-polymer						
	Castor Pre-polymer	Std. Pre-polymer	Castor Pre-polymer	Std. Pre-polymer	Castor Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
Type I TDI Dow Vornanate T-80	27	25	48.3	48.3		
Castor Oil Polyol	43				164	
Dow 3512 Polyol		50				49
Sundex 840 Process Oil	30	25			0	0
Totals:	100	100	7.8	10.2		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:	1:10.0					
Steam time:	1.5 mins					
Drying time:	48 hours					
Density:	6.6 pcf					
Laboratory Viscosities						
	Castor Oil Polyol		Dow Polyol 3512			
@ 77 Deg. F. (Unmixed):	400 cp		555 cp			
@ 69 Deg. F. (Initial Pre-polymer Mix):						
@ 75 Deg. F. (Initial Pre-polymer Mix):	50 cp		30 cp			
@ 90 Deg. F. Final Pre-polymer Mix (After 6 hours):	720 cp		50 cp			
@ 72 Deg. F. Final Pre-polymer Mix (After 60 hours):	2,470 cp					
@ 90 Deg. F. Final Pre-polymer Mix (After 60 hours):	710 cp					

Table 9: Comparison of a pre-polymer utilizing TDI and a castor oil polyol with a pre-polymer utilizing TDI and a petrochemical polyol

50 % Castor Pre-polymer						
	50% Castor Pre-polymer	Std. Pre-polymer	50% Castor Pre-polymer	Std. Pre-polymer	50% Castor Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
Type I TDI Dow Vornanate T-80	25	25	48.3	48.3		
Castor Oil Polyol	25				106.5	
Dow 3512 Polyol	25	50				49
Sundex 840 Process Oil	25	25			0	0
Totals:	100	100	8.1	10.2		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:	1:10.0					
Steam time:	1.5 mins					
Drying time:	48 hours					
Density:	13.4 pcf					
Laboratory Viscosities						
	50% Castor Oil Polyol		Dow Polyol 3512			
@ 77 Deg. F. (Unmixed):	400 cp		555 cp			
@ 69 Deg. F. (Initial Pre-polymer Mix):			750 cp			

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@ 75 Deg. F. (Initial Pre-polymer Mix):	70 cp	30 cp
@ 90 Deg. F. Final Pre-polymer Mix (After 6 hours):	890 cp	50 cp

Table 10: Comparison of a pre-polymer utilizing TDI and a castor oil polyol / petrochemical polyol blend with a pre-polymer utilizing TDI and a petrochemical polyol

[0095] As before, the experiment showed that vegetable oil polyol was less expensive than petrochemical polyol, but that the quality of the pre-polymer was better using vegetable oil polyol. Thus, the utilization of vegetable oil polyol in TDI based pre-polymers for bonded foam products represents an economically viable option.

EXAMPLE FOUR

[0096] A fourth experiment was conducted in an effort to further optimize the pre-polymer formulations. As with Example Two and Three, the experiment compared the pre-polymers utilizing TDI and one of the following polyols: soy oil polyol, castor oil polyol, a blend of soy oil polyol and petrochemical polyol, and a blend of castor oil polyol with petrochemical polyol. The viscosities of the four samples at various temperatures and times were also measured. As with the preceding examples, the TDI was Dow Vornanate T-80 Type I TDI, the soy oil polyol was Agrol 3.0, the castor oil polyol was CasChem #1 Imported, and the petrochemical polyol was Dow 3512, the characteristics of which are described above. The specific formulation for the pre-polymer with soy oil polyol was 162 pounds of TDI, 168 pounds of soy oil polyol, and 270 pounds of process oil, for a total of 600 pounds. The specific formulation for the pre-polymer with soy oil polyol / petrochemical polyol blend was 150 pounds of TDI, 180 pounds of 50:50 blended soy oil polyol and petrochemical polyol, and 270 pounds of process oil, for a total of 600 pounds. The specific formulation for the pre-polymer with castor oil polyol was 162 pounds of TDI, 210 pounds of castor oil polyol, and 228 pounds of process oil, for a total of 600 pounds. The specific formulation for the pre-polymer with castor oil polyol / petrochemical polyol blend was 150 pounds of TDI, 1740 pounds of castor oil

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polyol / petrochemical polyol blend, and 276 pounds of process oil, for a total of 600 pounds. The results of the comparison are shown below in Tables 11 through 14 below.

Soy Pre-polymer						
	Soy Pre-polymer	Std. Pre-polymer	Soy Pre-polymer	Std. Pre-polymer	Soy Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
Type I TDI Dow Vornanate T-80	27	25	48.3	48.3		
BioBased Soy Polyol	28				155	
Dow 3512 Polyol		50				49
Sundex 840 Process Oil	45	25			0	0
Totals:	100	100	9.8	10.2		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:	1.1:10.0					
Steam time:	1.5 mins					
Drying time:	48 hours					
Density:	6.6 pcf					
Laboratory Viscosities						
	BioBased Soy Polyol			Dow Polyol 3512		
@ 77 Deg. F. (Unmixed):	3570 cp			555 cp		
@ 69 Deg. F. (Initial Pre-polymer Mix):	70 cp			750 cp		
@ 75 Deg. F. (Initial Pre-polymer Mix):	50 cp			400 cp		
@ 90 Deg. F. Final Pre-polymer Mix (After 6 hours):	200 cp			1,100 cp		

Table 11: Comparison of a pre-polymer utilizing TDI and a soy oil polyol with a pre-polymer utilizing TDI and a petrochemical polyol

50 % Soy Pre-polymer						
	50% Soy Pre-polymer	Std. Pre-polymer	50% Soy Pre-polymer	Std. Pre-polymer	50% Soy Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
Type I TDI Dow Vornanate T-80	25	25	48.3	48.3		
BioBased Soy Polyol	30				102	
Dow 3512 Polyol		50				49
Sundex 840 Process Oil	45	25			0	0
Totals:	100	100	9.8	10.2		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:	1.1:10.0					
Steam time:	1.5 mins					
Drying time:	48 hours					
Density:	6.6 pcf					
Laboratory Viscosities						
	50% BioBased Soy Polyol			Dow Polyol 3512		
@ 77 Deg. F. (Unmixed):	3570 cp			555 cp		

Table 12: Comparison of a pre-polymer utilizing TDI and a soy oil polyol / petrochemical polyol blend with a pre-polymer utilizing TDI and a petrochemical polyol

Castor Pre-polymer						
	Castor Pre-polymer	Std. Pre-polymer	Castor Pre-polymer	Std. Pre-polymer	Castor Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #

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Type I TDI Dow Vornanate T-80	27	25	48.3	48.3		
Castor Oil Polyol	35				164	
Dow 3512 Polyol		50				49
Sundex 840 Process Oil	38	25			0	0
Totals:	100	100	8.7	10.2		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:	1.1:10.0					
Steam time:	1.5 mins					
Drying time:	48 hours					
Density:	6.6 pcf					
Laboratory Viscosities						
	Castor Oil Polyol			Dow Polyol 3512		
@ 77 Deg. F. (Unmixed):	400 cp			555 cp		
@ 75 Deg. F. (Initial Pre-polymer Mix):	30 cp			30 cp		
@ 90 Deg. F. Final Pre-polymer Mix (After 6 hours):	150 cp			50 cp		

Table 13: Comparison of a pre-polymer utilizing TDI and a castor oil polyol with a pre-polymer utilizing TDI and a petrochemical polyol

50 % Castor Pre-polymer						
	50% Castor Pre-polymer	Std. Pre-polymer	50% Castor Pre-polymer	Std. Pre-polymer	50% Castor Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
Type I TDI Dow Vornanate T-80	25	25	48.3	48.3		
Castor Oil Polyol	29				106.5	
Dow 3512 Polyol		50				49
Sundex 840 Process Oil	46	25			0	0
Totals:	100	100	9.8	9.9		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:	1.1:10.0					
Steam time:	1.5 mins					
Drying time:	48 hours					
Density:	6.6 pcf					
Laboratory Viscosities						
	50% Castor Oil Polyol			Dow Polyol 3512		
@ 77 Deg. F. (Unmixed):				555 cp		
@ 69 Deg. F. (Initial Pre-polymer Mix):				750 cp		

Table 14: Comparison of a pre-polymer utilizing TDI and a castor oil polyol / petrochemical polyol blend with a pre-polymer utilizing TDI and a petrochemical polyol

[0097] As before, the experiment showed that vegetable oil polyol was less expensive than petrochemical polyol, but that the quality of the pre-polymer was better using vegetable oil polyol. Thus, the utilization of vegetable oil polyol in TDI based pre-polymers for bonded foam products represents an economically viable option.

EXAMPLE FIVE

[0098] Pre-polymer prepared in accordance with castor oil polyol and soy oil polyol pre-polymer formulations illustrated in Example Four was used to create bonded foam logs using the aforementioned process. Physical testing of the 6 pcf samples showed that the castor oil polyol and the soy oil polyol pre-polymer formulations produced acceptable pads compared to the petrochemical polyol pre-polymer formulation. Center cut samples of the castor oil polyol and the soy oil polyol pre-polymer formulations showed very similar test results on all parameters when compared with the petrochemical polyol pre-polymer formulation. For example, bonded foam carpet underlayment produced using the petrochemical polyol pre-polymer formulation had a density of 6.6 pcf, CFD of 4.4 lbs, a compression set of 16.3 percent, a tensile strength of 9.9 lbs, and an elongation of 32.2 percent. By comparison, bonded foam carpet underlayment produced using the castor oil polyol pre-polymer formulation had a density of 6.3 pcf, a CFD of 4.7 lbs, a compression set of 14.2 percent, a tensile strength of 11.7 lbs, and an elongation of 31.7 percent. Similarly, bonded foam carpet underlayment produced using the soy oil polyol pre-polymer formulation had a density of 6.2 pcf, a CFD of 4.8 lbs, a compression set of 16.6 percent, and a tensile strength of 9.5 lbs. Overall, the bonded foam carpet underlayment produced using the castor oil polyol pre-polymer formulation had the greatest number of physical parameters that exceeded standard. A slight (0.5 percent) decrease in elongation was noted but was not deemed significant. Bonded foam produced using castor oil polyol and soy oil polyol pre-polymer formulations exhibited weaker adhesive strength as to the crumbs exiting the extruder onto the conveyor after steaming (e.g., in the continuous process described above), as measured by hand compression, than foam product produced using the petrochemical polyol pre-polymer formulation.

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However, after forced drying and curing for three hours, no problem remained and the bonded foam product could be slit and rolled up without any processing problems.

EXAMPLE SIX

[0099] A fifth experiment was conducted using two different pre-polymer formulations of TDI, castor oil polyol, and process oil. The laboratory tested the test samples for compression sets, compression force deflection (CFD), tensile strength, elongation, and density. The compression sets were tested in accordance with ASTM D-3574D-95. The CFD was tested in accordance with ASTM D-3574C-95. The tensile strength and elongation were tested in accordance with ASTM D-3574E-95. Finally, the density was tested in accordance with ASTM D-3574A-95. Tables 15 and 16 are the physical property test comparison results for bonded foam underlayment with a density of 6 pcf produced using the two castor oil polyol pre-polymer formulation. More specifically, Table 15 shows the physical properties of a bonded foam underlayment produced using a pre-polymer containing 27 percent TDI, 35 percent castor oil polyol, and 38 percent process oil. Table 16 shows the physical properties of a bonded foam underlayment produced using a pre-polymer containing 27 percent TDI, 43 percent castor oil polyol, and 30 percent process oil. The 27/35/38 pre-polymer formulation was used to produce 5 buns and the 27/43/30 pre-polymer formulation was used to produce 3 buns. The 27/35/38 pre-polymer formulation was calculated to have an 8.7 percent free isocyanate content after mixing for approximately 7 hours with a final pre-polymer formulation to crumb weight ratio of 8.98 percent. To compare the physical properties of the bonded foam underlayment produced using the petrochemical polyol pre-polymer formulation to bonded foam underlayment produced using the two castor oil polyol pre-polymer formulations, the samples were tested without back netting or any other type of physical reinforcement to eliminate any possible influence of the netting in reinforcing the pad.

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Castor Oil Polyol Pre-polymer Physical Property Comparative Analysis (without netting reinforcement)															
Sample:	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
Cut Position	Left														
	Density			CFD			Elongation			Tensile			Comp. Set		
Top		6.27			4.35			37.18			5.55			16.63	
Middle	5.88	5.93	0.05	5.13	6.33	1.20	34.53	43.26	8.73	2.95	6.17	3.22	15.12	15.16	0.04
Bottom		6.18			4.68			32.47			5.46			12.94	
Avg.		6.13			5.12			37.64			5.73			14.91	
High		6.27			6.33			43.26			6.17			16.63	
Low		5.93			4.35			32.47			5.46			12.94	
Range		0.34			1.98			10.79			0.71			3.69	
Sample:	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
Cut Position	Center														
	Density			CFD			Elongation			Tensile			Comp. Set		
Top		6.24			5.33			40.24			2.62			16.79	
Middle	6.14	6.12	(0.02)	5.25	5.68	0.43	33.79	28.76	(5.03)	3.02	3.33	0.31	14.52	13.00	(1.52)
Bottom		6.35			6.00			40.47			5.00			14.11	
Avg.		6.24			5.67			36.49			3.65			14.63	
High		6.35			6.00			40.47			5.00			16.79	
Low		6.12			5.33			28.76			2.62			13.00	
Range		0.23			0.67			11.71			2.38			3.79	
Sample:	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
Cut Position	Right														
	Density			CFD			Elongation			Tensile			Comp. Set		
Top		5.83			4.33			35.29			4.27			17.02	
Middle	6.02	6.01	(0.01)	5.33	5.05	(0.28)	35.68	40.29	4.61	3.42	4.12	0.70	14.22	14.38	0.16
Bottom		6.02			4.95			43.26			4.15			13.45	
Avg.		5.95			4.78			39.61			4.18			14.95	
High		6.02			5.05			43.26			4.27			17.02	
Low		5.83			4.33			35.29			4.12			13.45	
Range		0.19			0.72			7.97			0.15			3.57	
Composite Comparison:															
	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
	Density			CFD			Elongation			Tensile			Comp. Set		
Avg.	6.01	6.11	0.09	5.24	5.19	(0.05)	34.67	37.91	3.25	3.13	4.52	1.39	14.62	14.83	0.21
High	6.14	6.35	0.21	5.33	6.33	1.00	35.68	43.26	7.58	3.42	6.17	2.75	15.12	17.02	1.90
Low	5.88	5.83	(0.05)	5.13	4.33	(0.80)	33.79	28.76	(5.03)	2.95	2.62	(0.33)	14.22	12.94	(1.28)
Range	0.26	0.52	0.26	0.20	2.00	1.80	1.89	14.50	12.61	0.47	3.55	3.08	0.90	4.08	3.18
Std. Dev.	0.13	0.17	0.04	0.10	0.71	0.61	0.95	4.94	3.99	0.25	1.13	0.88	0.46	1.64	1.18
Number of Samples	3	9		3	9		3	9		3	9		3	9	

Table 15: Physical properties of a pre-polymer consisting of 27 percent TDI, 35 percent castor oil polyol, and 38 percent process oil

Castor Oil Polyol Pre-polymer Physical Property Comparative Analysis (without netting reinforcement)															
Sample:	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
Cut Position	Left														
	Density			CFD			Elongation			Tensile			Comp. Set		
Top		5.94			5.03			42.56			4.15			14.02	
Middle	5.88	5.87	(0.01)	5.13	5.33	0.20	34.53	46.00	11.47	2.95	6.33	3.38	15.12	15.36	0.24

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Bottom		6.01			4.78			35.59			3.49			12.43	
Avg.		5.94			5.05			41.38			4.66			13.94	
High		6.01			5.33			46.00			6.33			15.36	
Low		5.87			4.78			35.59			3.49			12.43	
Range		0.14			0.55			10.41			2.84			2.93	
Center															
Sample:	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
Cut Position	Center														
	Density			CFD			Elongation			Tensile			Comp. Set		
Top		6.10			4.43			37.38			4.35			15.22	
Middle	6.14	5.99	(0.15)	5.25	4.68	(0.57)	33.79	40.35	6.56	3.02	3.39	0.37	14.52	14.29	(0.23)
Bottom		6.32			4.75			41.06			4.26			14.04	
Avg.		6.14			4.62			39.60			4.00			14.52	
High		6.32			4.75			41.06			4.35			15.22	
Low		5.99			4.43			37.38			3.39			14.04	
Range		0.33			0.32			3.68			0.96			1.18	
Right															
Sample:	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
Cut Position	Right														
	Density			CFD			Elongation			Tensile			Comp. Set		
Top		6.20			4.15			40.68			6.81			13.77	
Middle	6.02	5.92	(0.10)	5.33	4.38	(0.95)	35.68	32.56	(3.12)	3.42	4.29	0.87	14.22	14.04	(0.18)
Bottom		6.11			4.33			39.74			3.42			14.26	
Avg.		6.08			4.29			37.66			4.84			14.02	
High		6.20			4.38			40.68			6.81			14.26	
Low		5.92			4.15			32.56			3.42			13.77	
Range		0.28			0.23			8.12			3.39			0.49	
Composite Comparison:															
	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
	Density			CFD			Elongation			Tensile			Comp. Set		
Avg.	6.01	6.05	0.04	5.24	4.65	(0.59)	34.67	39.55	4.88	3.13	4.50	1.37	14.62	14.16	(0.46)
High	6.14	6.32	0.18	5.33	5.33	0.00	35.68	46.00	10.32	3.42	6.81	3.39	15.12	15.36	0.24
Low	5.88	5.87	(0.01)	5.13	4.15	(0.98)	33.79	32.56	(1.23)	2.95	3.39	0.44	14.22	12.43	(1.79)
Range	0.26	0.45	0.19	0.20	1.18	0.98	1.89	13.44	11.55	0.47	3.42	2.95	0.90	2.93	2.03
Std. Dev.	0.13	0.14	0.01	0.10	0.37	0.27	0.95	3.94	2.99	0.25	1.24	0.99	0.46	0.85	0.39
Number of Samples	3	9		3	9		3	9		3	9		3	9	

Table 16: Physical properties of a pre-polymer consisting of 27 percent TDI, 43 percent castor oil polyol, and 30 percent process oil

[00100] During processing, the only notable difference in feel between the bonded foam produced using the petrochemical polyol pre-polymer formulation and the bonded foam produced using the two castor oil polyol pre-polymer formulations was a slightly lower hand strength exiting steaming on the conveyor for the bonded foam produced using the two castor oil polyol pre-polymer formulations. This difference, however, did not influence downstream processing like drying, curing, and slitting into finished bonded foam underlayment. There were not any processing problems despite the lower hand strength because the post steaming cure rate of both castor oil pre-polymer formulations were

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much more rapid than the petrochemical polyol pre-polymer formulation, which resulted in very good comparable physical properties.

[00101] Looking at the average composite data from all of the samples, the 27/35/38 pre-polymer formulation produced pad that had improved physical properties compared to standard for percent elongation and tensile strength. Compression set, CFD, and density were not significantly different than the bonded product produced using the petrochemical polyol. The 27/43/30 pre-polymer formulation also had improved percent elongation and tensile strengths compared to the petrochemical polyol pre-polymer formulation, but had slightly lower CFD and compression sets. The best physical property results came from the 27/35/38 pre-polymer formulation. Interestingly, this blend ratio was also the lowest cost due to less castor oil polyol needed in the pre-polymer formulation to achieve the best physical properties. It is projected that the utilization of the 27/35/38 pre-polymer formulation will result in a reduction of the cost of the pre-polymer by about 20 percent without any substantial decrease in physical properties.

EXAMPLE SEVEN

[00102] A sixth experiment was conducted using a different pre-polymer formulation of TDI, castor oil polyol, and process oil. The laboratory tested the test samples for compression sets, compression force deflection (CFD), tensile strength, elongation, and density. The compression sets were tested in accordance with ASTM D-3574D-95. The CFD was tested in accordance with ASTM D-3574C-95. The tensile strength and elongation were tested in accordance with ASTM D-3574E-95. Finally, the density was tested in accordance with ASTM D-3574A-95. Table 17 is the pre-polymer formulation for the sixth experiment. Tables 18 and 19 are the physical property test comparison results for bonded foam underlayment with a density of 5 pcf produced using the castor oil polyol pre-polymer formulation. More specifically, Table 18 shows the physical properties of a bonded foam

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underlayment produced using a pre-polymer containing 27 percent TDI, 38 percent castor oil polyol, and 35 percent process oil, and combined with the foam pieces at a weight ratio of 8.5 percent pre-polymer to foam pieces. Table 19 shows the physical properties of a bonded foam underlayment produced using a pre-polymer containing 27 percent TDI, 38 percent castor oil polyol, and 35 percent process oil, and combined with the foam pieces at a weight ratio of 8.5 percent pre-polymer to foam pieces.

Castor Pre-polymer						
	Castor Pre-polymer	Std. Pre-polymer	Castor Pre-polymer	Std. Pre-polymer	Castor Pre-polymer	Std. Pre-polymer
	Parts	Parts	% NCO	% NCO	OH #	OH #
Type I TDI Dow Vornanate T-80	27	25	48.3	48.3		
Castor Oil Polyol	38				164	
Dow 3512 Polyol		50				49
Sundex 840 Process Oil	35	25			0	0
Totals:	100	100	8.3	10.2		
Laboratory Processing						
Wt. Ratio of pre-polymer to foam crumbs:	9 percent					
Steam time:	1.5 mins					
Drying time:	48 hours					
Density:	5.2 pcf					
Laboratory Viscosities						
	Castor Oil Polyol			Dow Polyol 3512		
@ 77 Deg. F. (Unmixed):	400 cp			555 cp		
@ 75 Deg. F. (Initial Pre-polymer Mix):	50 cp			30 cp		
@ 90 Deg. F. Final Pre-polymer Mix (After 6 hours):	490 cp			50 cp		
@ 72 Deg. F. Final Pre-polymer Mix (After 60 hours):	2740 cp					
@ 90 Deg. F. Final Pre-polymer Mix (After 60 hours):	710 cp					

Table 17: Comparison of a pre-polymer utilizing TDI and a castor oil polyol with a pre-polymer utilizing TDI and a petrochemical polyol

Castor Oil Polyol Pre-polymer Physical Property Comparative Analysis (without netting reinforcement)															
Sample:	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
Cut Position	Top														
	Density			CFD			Elongation			Tensile			Comp. Set		
Left	6.27	5.82	-0.45	4.08	3.63	-0.45	36.03	37.88	1.85	16.30	15.76	-0.54	12.75	11.85	-0.90
Middle	6.38	5.96	-0.42	4.50	3.93	-0.57	35.68	35.71	0.03	15.72	13.56	-2.16	12.42	13.09	0.67
Right	6.19	5.81	-0.38	3.88	3.53	-0.35	33.26	40.29	7.03	14.77	14.00	-0.77	12.00	11.59	-0.41
Avg.		5.86			3.70			37.96			14.44			12.18	
High		5.96			3.93			40.29			15.76			13.09	
Low		5.81			3.53			35.71			13.56			11.59	
Range		0.15			0.40			4.58			2.20			1.50	
Sample:	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
Cut Position	Middle														
	Density			CFD			Elongation			Tensile			Comp. Set		
Left	5.58	5.40	-0.18	3.43	3.38	-0.05	41.00	34.79	-6.21	15.71	10.90	-4.81	12.52	12.47	-0.05

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Middle	5.69	5.76	0.07	3.28	3.88	0.60	41.18	43.24	2.06	16.96	15.02	-1.94	12.61	11.88	-0.73
Right	5.48	5.51	0.03	3.28	4.30	1.02	40.56	46.38	5.82	15.23	5.88	-9.35	13.22	12.26	-0.96
Avg.		5.56			3.85			41.47			10.60			12.20	
High		5.76			4.30			46.38			15.02			12.47	
Low		5.40			3.38			34.79			5.88			11.88	
Range		0.36			0.92			11.59			9.14			0.59	
Sample:	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
Cut Position	Bottom														
	Density			CFD			Elongation			Tensile			Comp. Set		
Left	5.55	5.75	0.20	3.23	3.90	0.67	40.47	36.38	-4.09	15.43	14.49	-0.94	13.52	11.30	-2.22
Middle	5.67	5.81	0.14	3.20	4.13	0.93	36.92	35.26	-1.66	15.89	7.30	-8.59	14.17	12.32	-1.85
Right	5.53	5.75	0.22	3.10	3.85	0.75	42.12	38.41	-3.71	16.47	16.47	0.00	12.36	11.37	-0.99
Avg.		5.77			3.96			36.68			12.75			11.66	
High		5.81			4.13			38.41			16.47			12.32	
Low		5.75			3.85			35.26			7.30			11.30	
Range		0.06			0.28			3.15			9.17			1.02	

Table 18: Physical properties of 5 pcf foam bun with 8.5 percent pre-polymer

Castor Oil Polyol Pre-polymer Physical Property Comparative Analysis (without netting reinforcement)															
Sample:	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
Cut Position	Left														
	Density			CFD			Elongation			Tensile			Comp. Set		
Top	6.27	5.82	(0.45)	4.08	3.78	(0.30)	36.03	49.41	13.38	16.30	17.79	1.49	12.75	13.71	0.96
Middle	6.38	5.51	(0.87)	4.50	3.93	(0.57)	35.68	44.85	9.17	15.72	17.42	1.70	12.42	15.85	3.43
Bottom	6.19	6.02	(0.17)	3.88	3.85	(0.03)	33.26	37.50	4.24	14.77	14.31	(0.46)	12.00	13.18	1.18
Avg.	6.28	5.78	(0.50)	4.15	3.85	(0.30)	34.99	43.92	8.93	15.60	16.51	0.91	12.39	14.25	1.86
High	6.38	6.02		4.50	3.93		36.03	49.41		16.30	17.79		12.75	15.85	
Low	6.19	5.51		3.88	3.78		33.26	37.50		14.77	14.31		12.00	13.18	
Range	0.19	0.51		0.62	0.15		2.77	11.91		1.53	3.48		0.75	2.67	
Sample:	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
Cut Position	Center														
	Density			CFD			Elongation			Tensile			Comp. Set		
Top	5.58	5.12	(0.46)	3.43	3.68	0.25	41.00	43.18	2.18	15.71	16.52	0.81	12.52	14.60	2.08
Middle	5.69	5.46	(0.23)	3.28	3.58	0.30	41.18	45.24	4.06	16.96	15.53	(1.43)	12.61	14.53	1.92
Bottom	5.48	5.19	(0.29)	3.28	3.65	0.37	40.56	35.12	(5.44)	15.23	12.61	(2.62)	13.22	13.93	0.71
Avg.	5.58	5.26	(0.33)	3.33	3.64	0.31	40.91	41.18	0.27	15.97	14.89	(1.08)	12.78	14.35	1.57
High	5.69	5.46		3.43	3.68		41.18	45.24		16.96	16.52		13.22	14.60	
Low	5.48	5.12		3.28	3.58		40.56	35.12		15.23	12.61		12.52	13.93	
Range	0.21	0.34		0.15	0.10		0.62	10.12		1.73	3.91		0.70	0.67	
Sample:	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.	Std.	Test	Diff.
Cut Position	Right														
	Density			CFD			Elongation			Tensile			Comp. Set		
Top	5.55	5.30	(0.25)	3.23	3.28	0.05	40.47	39.29	(1.18)	15.43	16.21	0.78	13.52	14.11	0.59
Middle	5.67	5.23	(0.44)	3.20	3.03	(0.17)	36.92	39.29	2.37	15.89	15.26	(0.63)	14.17	14.37	0.20
Bottom	5.53	5.12	(0.41)	3.10	3.53	0.43	42.12	42.03	(0.09)	16.47	15.47	(1.00)	12.36	14.95	2.59
Avg.	5.58	5.22	(0.37)	3.18	3.28	0.10	39.84	40.20	0.37	15.93	15.65	(0.28)	13.35	14.48	1.13
High	5.67	5.30		3.23	3.53		42.12	42.03		16.47	16.21		14.17	14.95	
Low	5.53	5.12		3.10	3.03		36.92	39.29		15.43	15.26		12.36	14.11	
Range	0.14	0.18		0.13	0.50		5.20	2.74		1.04	0.95		1.81	0.84	
Grand Average	5.82	5.42	(0.40)	3.55	3.59	0.04	38.58	41.77	3.19	15.83	15.68	(0.15)	12.84	14.36	1.52

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Table 19: Physical properties of 5 pcf foam bun with 9.2 percent pre-polymer

EXAMPLE EIGHT

[00103] In one embodiment, the prime polyurethane foam was prepared using the formulation shown in Table 20:

Component	Example	Amount (pph)
Polyol	Base 3000 MW Polyol (BASF)	79
Polyol	Polyol 3400	20
Isocyanate	TDI 80/20	49.37
Fire Retardant	Melamine	10
Fire Retardant	CP-2	15.5
Surfactant	L-650	0.85
Catalyst	TCAT 150	0.35
Catalyst	ZF-10	0.15
Catalyst	C 324	0.15
Water	Water	3.5
Anti-microbial	DM-50	0.25
Color	Blue	0.0043
Color	Yellow	0.0035
Color	Orange	0.0123

Table 20

[00104] The formulation in Table 1 had an isocyanate index of 109.

EXAMPLE NINE

[00105] In one embodiment, the prime polyurethane foam was prepared using the formulation shown in Table 21:

Component	Example	Amount (pph)
Polyol	Base 3000 MW Polyol (BASF)	79
Polyol	Polyol 3400	20
Isocyanate	TDI 80/20	49.37
Fire Retardant	Melamine	10
Fire Retardant	HF-4	15.5
Catalyst	TCAT 150	0.35
Catalyst	ZF-10	0.15
Catalyst	C 324	0.15
Surfactant	L-650	0.85
Water	Water	3.5
Anti-microbial	DM-50	0.25

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Color	Blue	0.0043
Color	Yellow	0.0035
Color	Orange	0.0123

Table 21

[00106] The formulation in Table 2 had an isocyanate index of 109.

EXAMPLE TEN

[00107] In one embodiment, the prime polyurethane foam was prepared using the formulation shown in Table 22:

Component	Example	Amount (pph)
Polyol	Base 3000 MW Polyol (BASF)	79
Polyol	Polyol 3400	20
Isocyanate	TDI 80/20	49.96
Fire Retardant	Melamine	10
Fire Retardant	HF-4	15.5
Catalyst	TCAT 150	0.6
Catalyst	ZF-10	0.15
Catalyst	C 324	0.15
Surfactant	L-650	0.85
Water	Water	3.6
Anti-microbial	DM-50	0.25
Color	Blue	0.0043
Color	Yellow	0.0035
Color	Orange	0.0123

Table 22

[00108] The formulation in Table 3 had an isocyanate index of 108.

EXAMPLE ELEVEN

[00109] In one embodiment, the prime polyurethane foam was prepared using the formulation shown in Table 23:

Component	Example	Amount (pph)
Polyol	Base 3000 MW Polyol (BASF)	79
Polyol	Polyol 3400	20
Polyol	DP-1022	1
Isocyanate	TDI 80/20	52.04
Fire Retardant	Melamine	10
Fire Retardant	HF-4	15.5

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Catalyst	TCAT 150	0.68
Catalyst	ZF-10	0.1
Catalyst	C 324	0.2
Surfactant	L-650	0.85
Water	Water	3.6
Anti-microbial	DM-50	0.25
Color	Blue	0.0043
Color	Yellow	0.0035
Color	Orange	0.0123

Table 23

[00110] The formulation in Table 4 had an isocyanate index of 108.

EXAMPLE TWELVE

[00111] A fifth experiment was conducted using the formulations given in Examples 9 and 11. The laboratory tested the test samples for 50% and 90% compression sets, tensile strength, elongation, and density. The compression sets were tested in accordance with ASTM D-3574D-95. The tensile strength and elongation were tested in accordance with ASTM D-3574E-95. Finally, the density was tested in accordance with ASTM D-3574A-95. Tables 5 and 6 are the physical property test results for the samples produced using the vegetable oil polyol formulations given in Examples 9 and 11, respectively.

	Density (pcf)	IFD (25%, pounds)	Airflow (cfm)	50% C SET	90% C SET
Top	1.93	36.8	6	6.54	7.38
Middle	1.93	34.9	5.8	5.51	8.99
Bottom	1.98	31.3	5.2	4.24	10.41
Avg.	1.95	34.3	5.7	5.43	8.93
High	1.98	36.8	6	6.54	10.41
Low	1.93	31.3	5.2	4.21	7.38
Range	0.05	5.5	0.8	2.33	3.03
Tensile Strength (pounds)	12.68				
Tear Strength (pounds)	2.55				
Elongation (5)	155.91				

Table 24

	Density (pcf)	IFD (25%, pounds)	Airflow (cfm)	50% C SET	90% C SET
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Top	1.8	30	3.2	8.69	57.71
Middle	1.85	34.2	2.1	15.1	49.09
Bottom	1.87	32	2	17.69	74.54
Avg.	1.84	32.1	2.43	13.83	60.45
High	1.87	34.2	3.2	07.69	74.54
Low	1.8	30	2.0	8.69	49.09
Range	0.07	4.2	1.2	9.0	25.45
Tensile Strength (pounds)	16.84				
Tear Strength (pounds)	2.8				
Elongation (5)	181.5				

Table 25

[00112] The fatigue loss in percent thickness for the formulation in Examples 9 and 11 are 2.94 and 1.5 percent respectively while the IFD was 24.5 pounds and 28.5 pounds respectively. The formulation given in Example 11 had no discernible odor.

[00113] The invention having been generally described, the examples are given as particular embodiments of the invention and to demonstrate the practice and advantages thereof.

[00114]

Where numerical ranges or limitations are expressly stated, such express ranges or limitations should be understood to include iterative ranges or limitations of like magnitude falling within the expressly stated ranges or limitations (e.g., from about 1 to about 10 includes, 2, 3, 4, etc.; greater than 0.10 includes 0.11, 0.12, 0.13, etc.). Use of the term “optionally” with respect to any element of a claim is intended to mean that the subject element is required, or alternatively, is not required. Both alternatives are intended to be within the scope of the claim. Use of broader terms such as “comprises”, “includes”, “having”, and the like should be

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understood to provide support for narrower terms such as “consisting of”, “consisting essentially of”, “comprised substantially of” and the like.

[00115] The discussion of a reference herein is not an admission that it is prior art to the present invention, especially any reference that may have a publication date after the priority date of this application.

[00116] The scope of claim should not be limited by the preferred embodiment set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

CLAIMS

1. A pre-polymer for use as a binder in the manufacture of a bonded foam product comprising: a non-acidified isocyanate and a vegetable oil polyol; wherein the pre-polymer is substantially free of any petrochemical polyol.
2. The pre-polymer of claim 1 further comprising: a process oil; wherein the process oil is added to the pre-polymer to modify the viscosity of the pre-polymer to between about 100-800 cP at about 69-95 °F.
3. The pre-polymer of claim 2 comprising between about 22 percent and about 32 percent of the isocyanate, between about 33 percent and about 43 percent of the vegetable oil polyol, and between about 30 percent and about 40 percent of the process oil.
4. The pre-polymer of claim 3 wherein the vegetable oil polyol is derived from a vegetable oil, and wherein the chemical structure of the vegetable oil is not substantially modified to form the vegetable oil polyol.
5. The pre-polymer of claim 4 wherein the vegetable oil polyol is castor oil polyol.
6. The pre-polymer of claim 1 wherein the viscosity of the pre-polymer is less than about 1,000 centipoise at about 90 °F.
7. The pre-polymer of claim 6 wherein the viscosity of the pre-polymer is less than about 1,000 centipoise at about 90 °F about 60 hours after combining the isocyanate and the vegetable oil polyol.
8. The pre-polymer of claim 7 further comprising: an antimicrobial chemical compound that discourages the growth of mildew and mold in a product manufactured with the pre-polymer.
9. The pre-polymer of claim 8 further comprising: a dimorpholinodiethylether catalyst that reduces the amount of moisture required to cure the pre-polymer.
10. A bonded foam product manufactured with the pre-polymer of any one of claims 1-9.
11. A method for making a bonded foam product, the method comprising: coating a plurality of foam pieces with a pre-polymer, the pre-polymer comprising a non-acidified isocyanate and a vegetable oil polyol, wherein the pre-polymer is substantially free of any petrochemical polyol; compressing the foam pieces into a foam log of a desired density; and steaming the foam log to cure the pre-polymer.

12. The method of claim 11 wherein the pre-polymer further comprises a process oil; wherein the process oil is added to the pre-polymer to modify the viscosity of the prepolymer to between 400-600 cP at about 69-95 °F.
13. The method of claim 12 wherein the pre-polymer comprises between about 22 percent and about 32 percent of the isocyanate, between about 33 percent and about 43 percent of the vegetable oil polyol, and between about 30 percent and about 40 percent of the process oil; and wherein the bonded foam product has a density of at least about 4 pcf.
14. The method of claim 12 wherein the pre-polymer comprises between about 22 percent and about 32 percent of the isocyanate, between about 35 percent and about 45 percent of the vegetable oil polyol, and between about 28 percent and about 38 percent of the process oil; and wherein the bonded foam product has a density of less than about 4 pcf.
15. The method of claim 11 wherein the pre-polymer further comprises an antimicrobial chemical compound that discourages the growth of mildew and mold in a product manufactured with the pre-polymer.
16. The method of claim 11 wherein the vegetable oil polyol is derived from a vegetable oil, and wherein the chemical structure of the vegetable oil is not substantially modified to form the vegetable oil polyol.
17. The method of claim 16 wherein the vegetable oil polyol is castor oil polyol.
18. The method of claim 11 wherein the viscosity of the pre-polymer is less than about 1,000 centipoise at about 90 °F.
19. The method of claim 11 wherein the viscosity of the pre-polymer is less than about 1,000 centipoise at about 90 °F about 60 hours after combining the isocyanate and the vegetable oil polyol.
20. A bonded foam underlayment manufactured according to the method of any one of claims 11-19.
21. A bonded polyurethane foam made from a pre-polymer formulation which includes between about 5 percent and about 95 percent of a vegetable oil polyol, and a non-acidified isocyanate, and wherein the pre-polymer formulation is substantially free of petrochemical polyol.

22. The polyurethane foam of claim 21, wherein said formulation comprises between about 5 percent and about 25 percent of said vegetable oil polyol.
23. The polyurethane foam of claim 21, wherein said vegetable oil polyol has a hydroxyl number between about 150 mg KOH/g and about 175 mg KOH/g.
24. The polyurethane foam of claim 21, wherein said vegetable oil polyol has a hydroxyl number between about 50 mg KOH/g and about 60 mg KOH/g.
25. The polyurethane foam of claim 21, wherein said vegetable oil polyol has an acid value between about 4 mg KOH/g and about 9 mg KOH/g.
26. The polyurethane foam of claim 21, wherein said vegetable oil polyol has an acid value of not more than about 3 mg KOH/g.
27. The polyurethane foam of claim 21, wherein said vegetable oil polyol is a castor oil polyol.
28. The polyurethane foam of claim 21, wherein said vegetable oil polyol is a soy oil polyol.
29. The polyurethane foam of claim 21, wherein said vegetable oil polyol is a castor oil polyol having a generally clear color.
30. The pre-polymer of claim 1 wherein the isocyanate has an acidity of less than or equal to about 40 parts-per-million (ppm) hydrogen chloride.
31. The pre-polymer of claim 1 wherein the prepolymer comprises about 8 to about 10 weight percent free isocyanates.
32. The method of claim 11 wherein the isocyanate has an acidity of less than or equal to about 40 parts-per-million (ppm) hydrogen chloride.
33. The method of claim 11 wherein the prepolymer comprises about 8 to about 10 weight percent free isocyanates prior to coating the foam pieces.
34. The method of claim 13 wherein the bonded foam product has a density between about 4-8 pcf.
35. The method of claim 14 wherein the bonded foam product has a density of about 3 pcf.
36. The method of claim 11 wherein compressing the foam pieces into a foam log utilizes a compression ratio between about 38:28 to 52:28.

37. The bonded polyurethane foam of claim 21 wherein the pre-polymer comprises between about 22 percent and about 32 percent of the isocyanate, between about 33 percent and about 43 percent of the vegetable oil polyol, and between about 30 percent and about 40 percent of the process oil; and wherein the bonded foam product has a density between about 4-8 pcf.

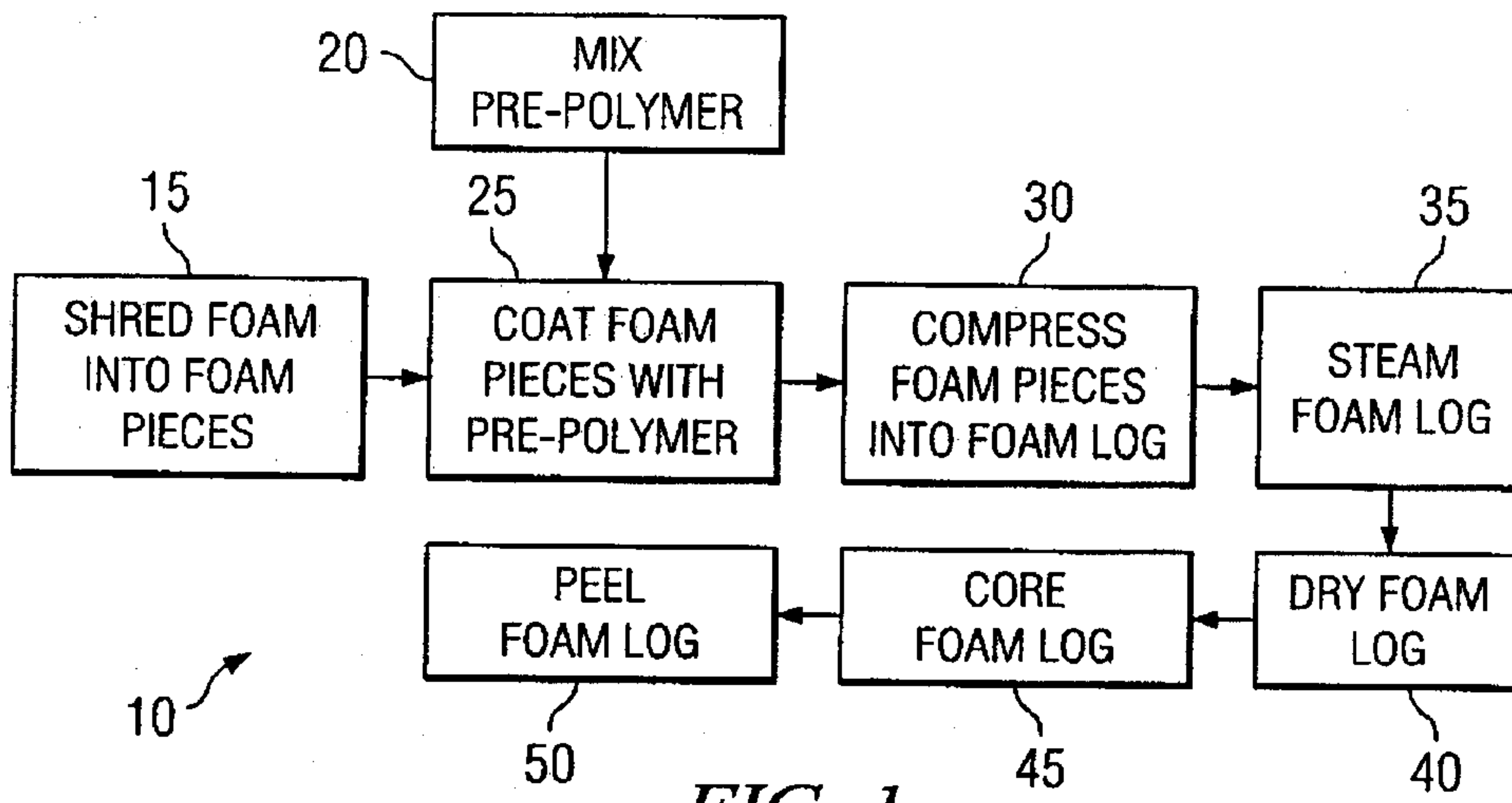


FIG. 1

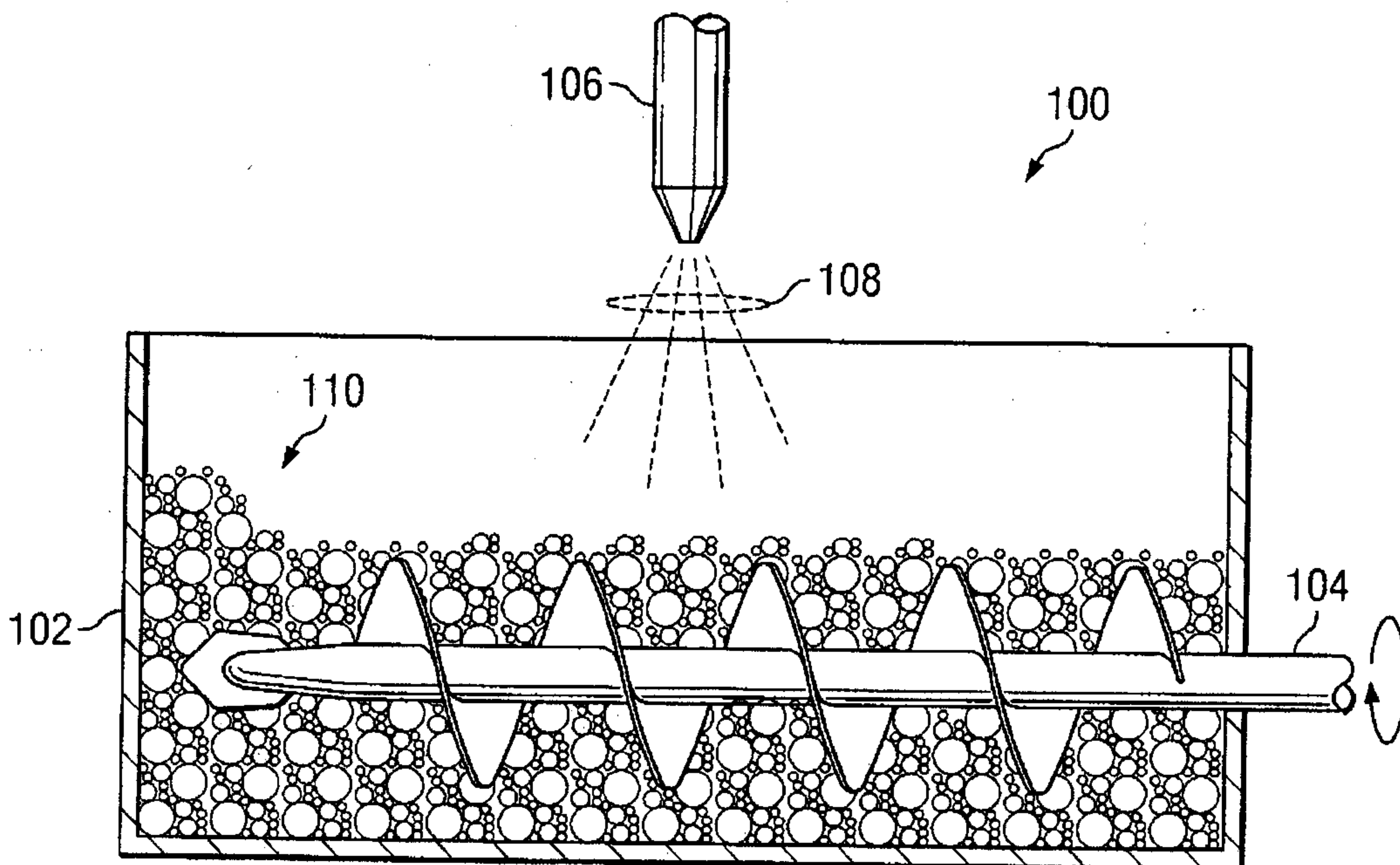


FIG. 2

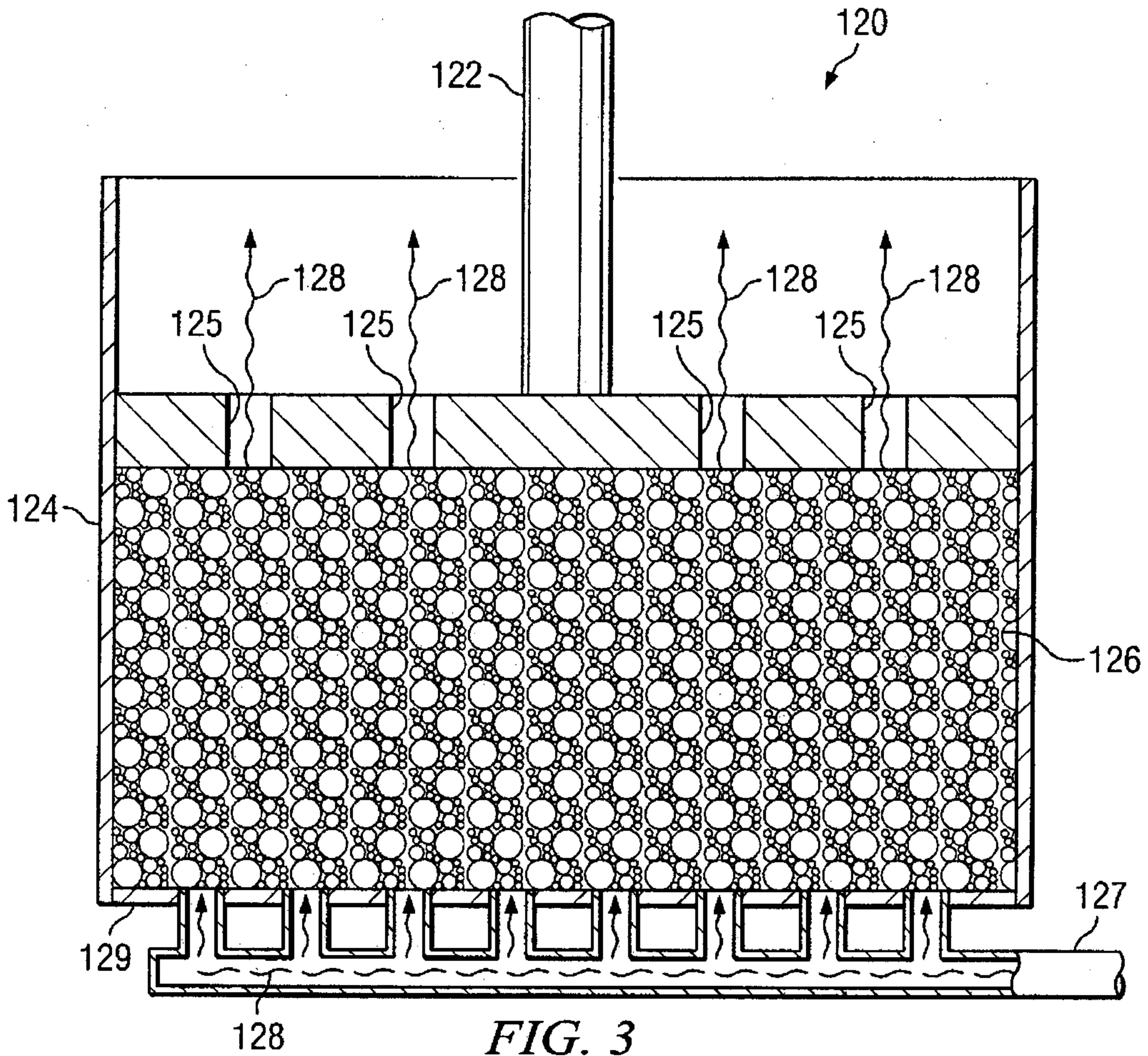


FIG. 3

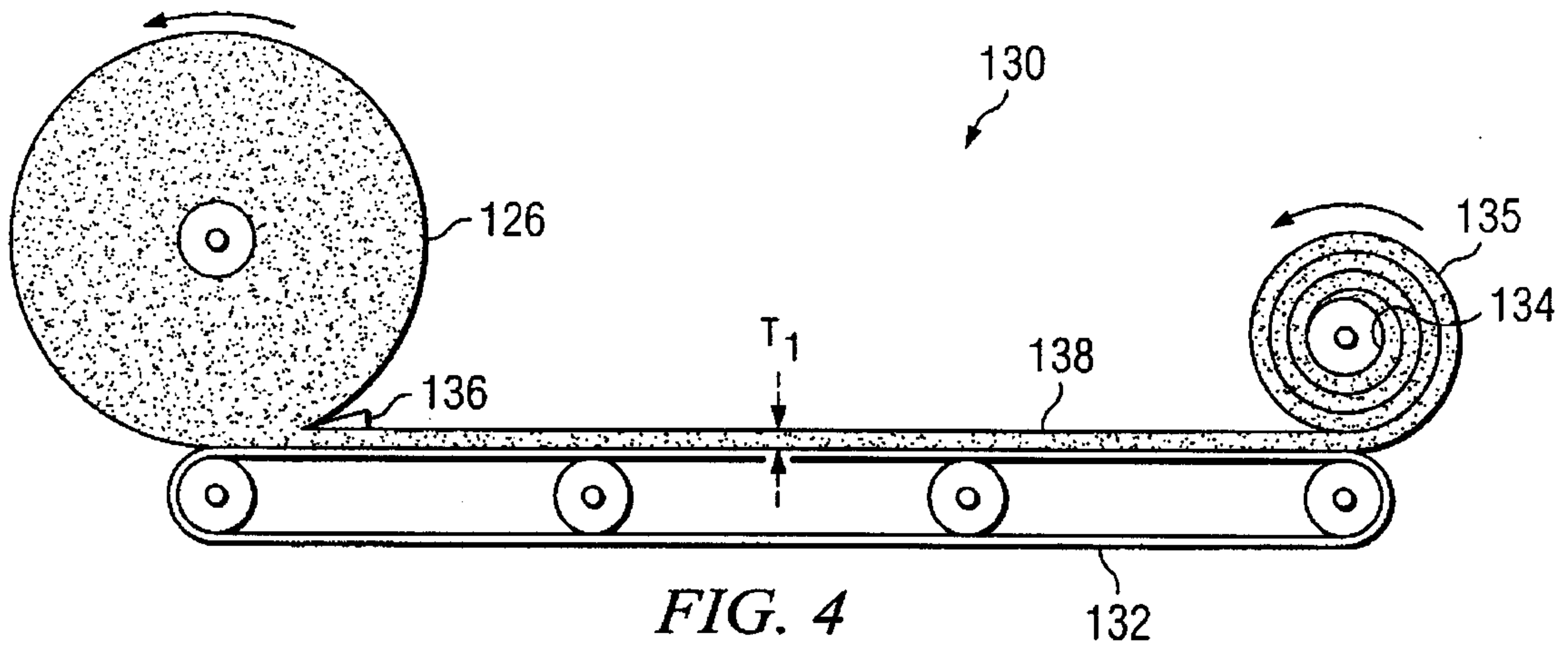


FIG. 4

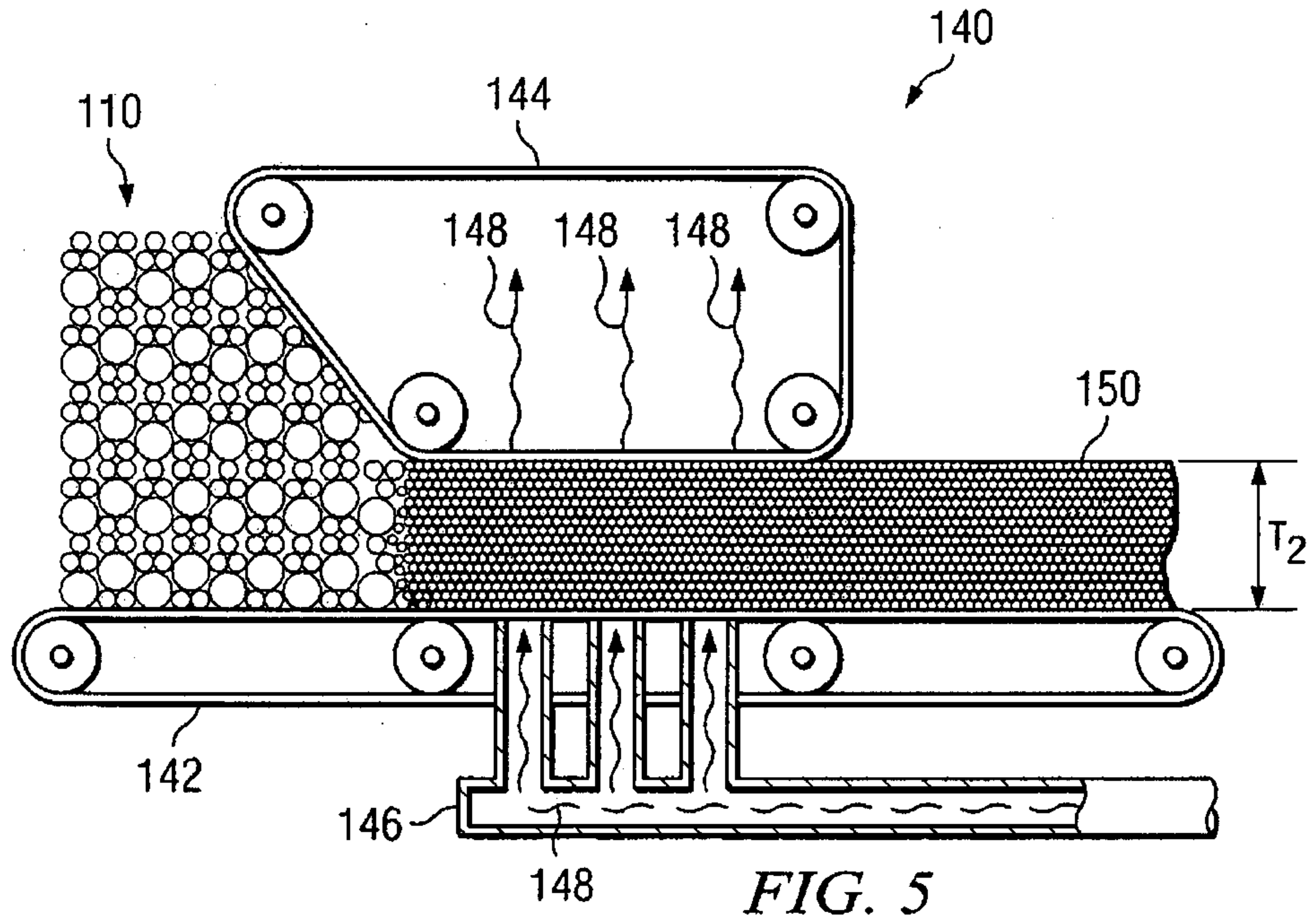


FIG. 5

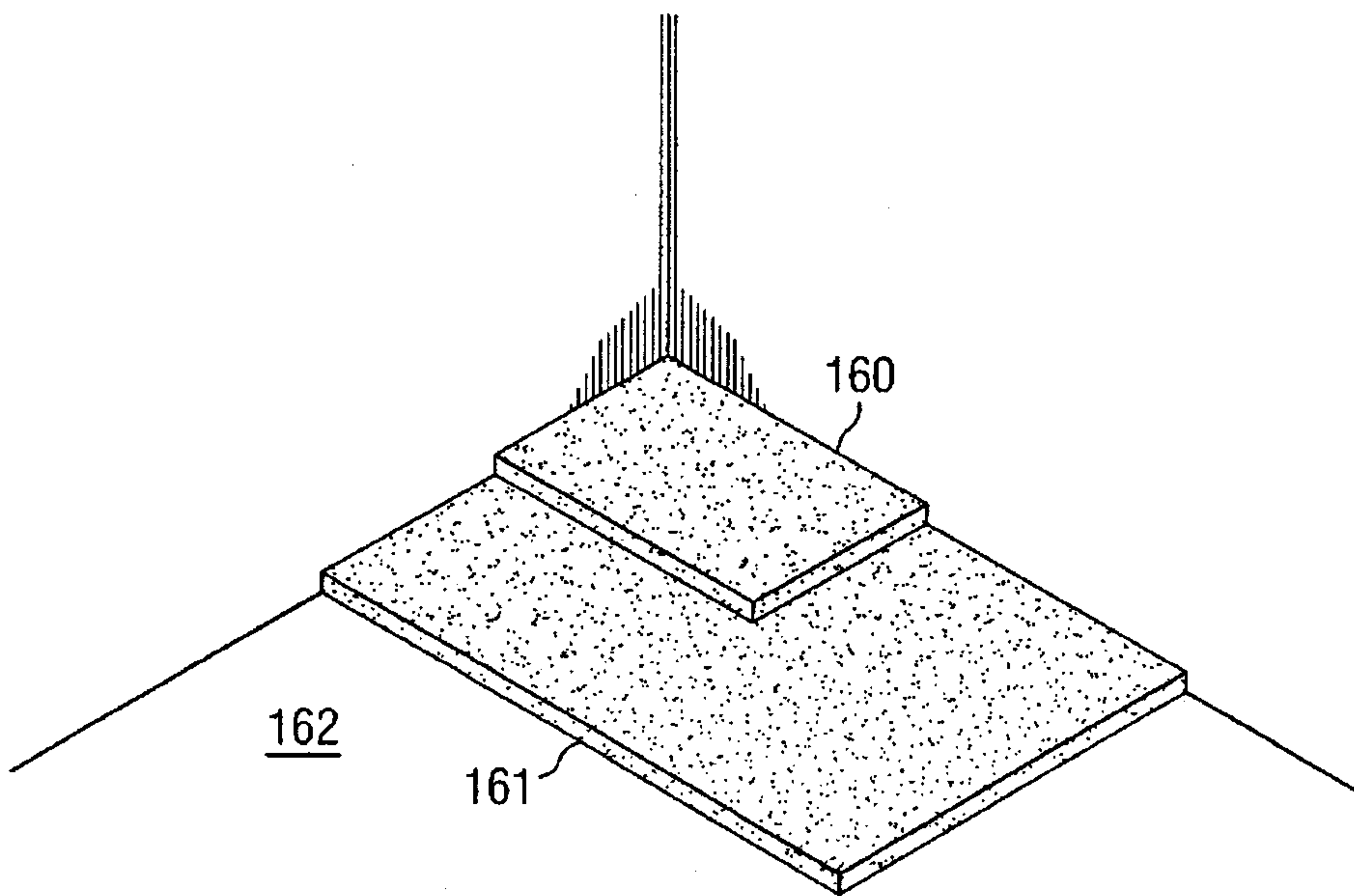


FIG. 6

300
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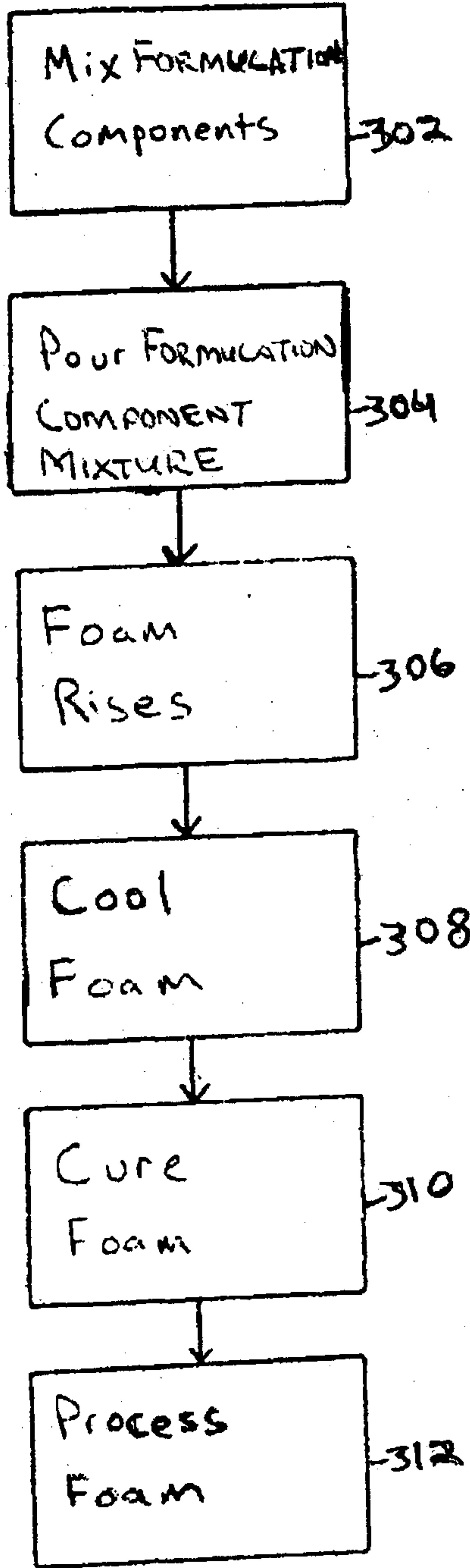


FIG. 7

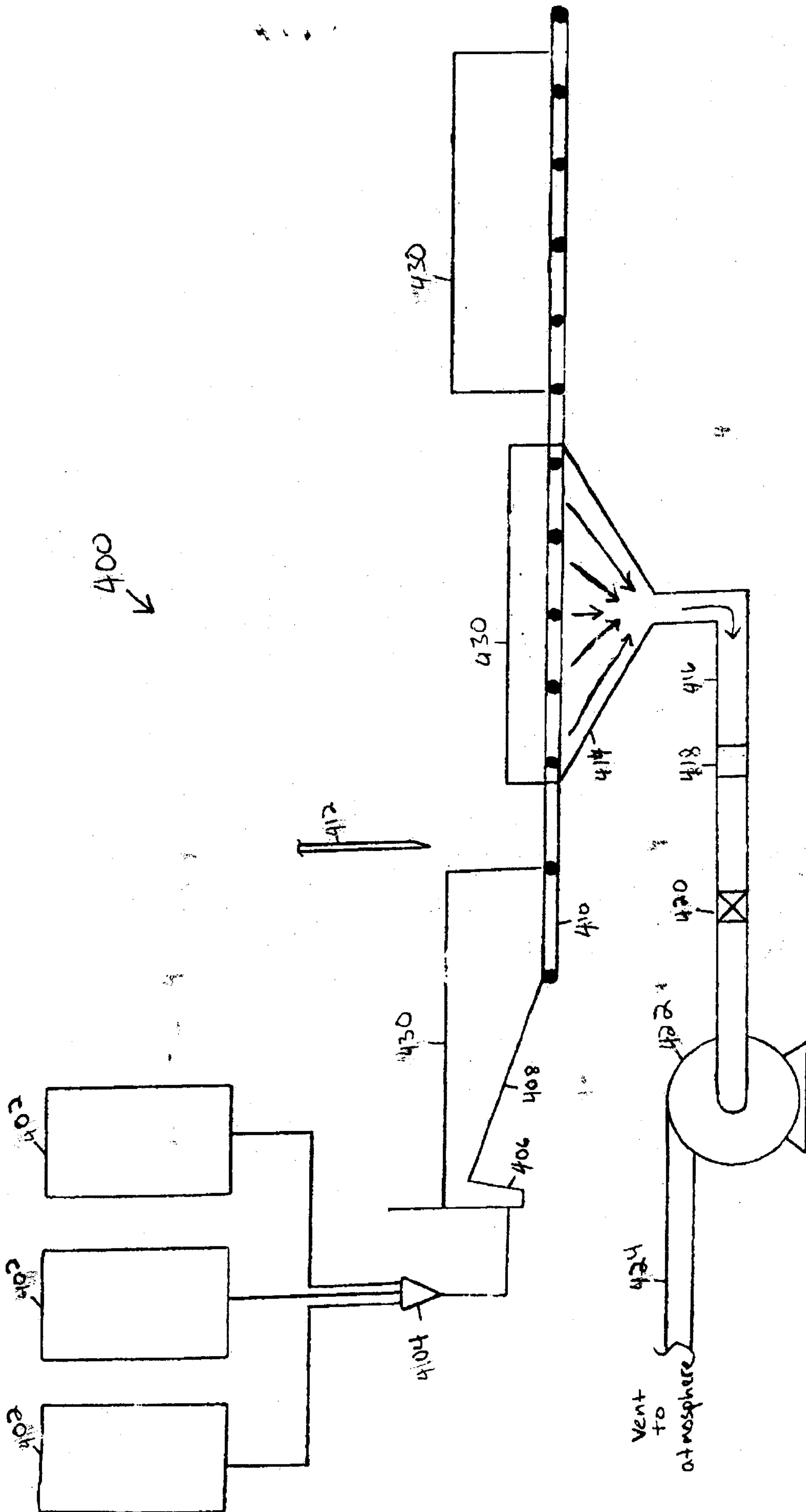


FIG. 8

