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(54) Title: COMPRESSED POLYMER FOAMS AND PANELS CONTAINING THEM

(57) **Abrégé/Abstract:**

Disclosed is a compressed, evacuated, open-cell polymer foam, the foam having an open cell content of 70 percent or more, the foam having a thickness of 40 to 90 percent of the initial thickness of the foam prior to compression, the foam having an absolute cell gas pressure of 10 torr or less in its open cells, the foam having a density of 16 to 250 kilograms per cubic meter. Further disclosed is an evacuated insulation panel employing the foam.



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(21) International Application Number: PCT/US96/19210 (22) International Filing Date: 21 November 1996 (21.11.96) (30) Priority Data: 08/595,780 2 February 1996 (02.02.96) US (71) Applicant: THE DOW CHEMICAL COMPANY [US/US]; 2030 Dow Center, Abbott Road, Midland, MI 48640 (US). (72) Inventor: MALONE, Bruce, A.; 3130 Granview Drive, Granville, OH 43023 (US). (74) Agent: DEAN, J., Robert., Jr.; The Dow Chemical Company, Patent Dept., P.O. Box 515, Granville, OH 43023-0515 (US).		(81) Designated States: CA, FI, JP, KR, MX, NO, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report.</i>
(54) Title: COMPRESSED POLYMER FOAMS AND PANELS CONTAINING THEM (57) Abstract Disclosed is a compressed, evacuated, open-cell polymer foam, the foam having an open cell content of 70 percent or more, the foam having a thickness of 40 to 90 percent of the initial thickness of the foam prior to compression, the foam having an absolute cell gas pressure of 10 torr or less in its open cells, the foam having a density of 16 to 250 kilograms per cubic meter. Further disclosed is an evacuated insulation panel employing the foam.		

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COMPRESSED POLYMER FOAMS AND PANELS CONTAINING THEM

This invention relates to compressed, extruded, evacuated open-cell polymer foams and evacuated insulation panels containing them.

5 To significantly improve the performance of insulating systems, evacuated or vacuum panel technology is currently being evaluated by industry. The absence of air or gas in the panels affords the possibility of substantial enhancement of insulating performance.

10 A useful evacuated panel system is one employing a panel corestock of a rigid open-cell foam. The open-cell structure of the foam allows rapid and substantially complete withdrawal of gases from within the foam structure and the panel. The rigid foam matrix provides a corestock
15 of substantial mechanical strength and performance.

Using open-cell foams in evacuated insulation panels, it has been possible to obtain R values of 10 to 15 per inch of thickness depending upon the evacuation or vacuum level, polymer type, cell size, density, and open
20 cell content of the foam.

It would be desirable to achieve yet higher insulation capability (lower thermal conductivity) in evacuated panels employing open-cell foams.

According to the present invention, there is a
25 compressed, evacuated, open-cell polymer foam. The foam has: a) an open cell content of 70 percent or more prior to compression; b) a thickness of 40 to 90 percent of the initial thickness or volume of the foam prior to compression; c) an absolute cell gas pressure of 10 torr or
30 less in its open cells; and d) a density of 16 to 250

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kilograms per cubic meter (kg/cm^3) prior to compression. Surprisingly, the foam affords similar insulating performance after compression as before compression. The similar performance after compression results in significantly enhanced insulating performance or heat resistance on a per unit thickness or volume basis compared to the foam before compression.

According to the present invention, there is an evacuated foam insulation panel. The panel comprises a compressed, open-cell foam and a receptacle capable of enclosing the foam and being hermetically sealed. The foam is situated within the receptacle. The interior of the receptacle has an absolute pressure of 10 torr or less. The foam has an open cell content of 70 percent or more prior to (before) compression and a thickness of 40 to 90 percent of its initial thickness prior to compression.

According to another aspect of the present invention, there is provided a method for enhancing the insulating capability of a polymer foam on a per-unit thickness basis, the method comprising the following steps: a) providing an open cell polymer foam of 70 percent or more open cell content and having a density of 16 to 250 kilograms per cubic meter; b) compressing the foam to a thickness of 30 to 90 percent of the initial thickness of the foam prior to compression; and c) evacuating the foam to an absolute cell gas pressure of 10 torr or less in its open cells.

According to still another aspect of the present invention there is provided a foam obtainable by a method described herein.

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According to yet another aspect of the present invention, there is provided a foam insulation panel, as described herein incorporating this foam.

It was found surprising the insulating performance
5 of an evacuated, open-cell polymer foam could be maintained
after compression of the foam. The resistance of the
compressed foam to heat flow was similar to that of the foam
before compression (uncompressed foam). An uncompressed
foam is a foam which has not been substantially compressed
10 subsequent to its manufacture and cure to a permanent form.

The maintenance of a similar degree of resistance to heat flow after compression is advantageous because similar insulating performance can be obtained with a lesser thickness or volume of foam or greater insulating performance can be obtained by adding additional
5 foam to reconstitute to the original thickness before compression or any other thickness greater than the thickness of the compressed foam. Either way, the insulating performance of the foam on a per unit thickness basis is enhanced by compression of the foam.

With the present invention, it was found possible to significantly enhance the performance of evacuated insulation panels employing open-cell foams as a corestock.
10 Previously, it was possible to obtain R values of up to 15 per inch of foam thickness. Now, it is possible to obtain R values of up to 40 per inch of foam thickness. Attainable R value varies according to evacuation or vacuum level, polymer type, cell size, density, and open cell content of the foam. R value is the reciprocal of thermal conductivity based upon the thermal conductivity units of BTU-in/ft²-hr-°F (British Thermal Units inch per square foot per hour per
15 degree Fahrenheit).

The level of compression impacts the degree to which resistance to heat flow is maintained after compression, and, ultimately, the extent to which insulating performance on a per unit thickness or volume basis is enhanced. If the foam is compressed too little, the benefit of retaining similar insulating performance in as reasonably small a thickness or volume
20 as possible is not realized. If the foam is compressed too much, its insulating performance compared to the uncompressed foam dissipates so much that its insulating performance on a per unit thickness or volume basis is not further enhanced. Further, with too much compression, foam mechanical properties may become denuded.

The foams are desirably compressed to 30 to 90 percent, preferably from 40 to 70
25 percent, and more preferably 50 to 60 percent of their initial (original) thickness or volume prior to compression. The preceding extent of compression ranges are generalized. Desired compression levels will be a function of polymer identity, foam physical properties, level of evacuation, and desired insulating performance.

It is desirable to have or to maintain as high an open cell content as possible. The
30 higher the open cell content, the greater the level of evacuation or vacuum possible in the foam. The greater the level of evacuation, the lower the potential thermal conductivity and the greater the resistance to heat flow. The present foam has an open cell content of 70 percent or more, preferably 90 percent or more, and most preferably 95 percent or more prior to compression according to ASTM D2856-A. The foam is preferably as close as possible to
35 complete or 100 percent open cell. The open cell content after compression will be equal to or greater than the open cell content prior to or before compression.

An evacuated foam is a foam having within its open cells a partial vacuum or near total vacuum of subatmospheric absolute pressure. The present foam has an absolute pressure

of 10 torr or less, more preferably 1 torr or less, and most preferably 0.1 torr or less in its open cells.

5 The foam prior to compression (uncompressed foam) has a density of 16 to 250 kg/cm³ and most preferably 25 to 100 kg/cm³ according to ASTM D-1622-88. Density will increase proportionately with the extent of compression.

10 In the prior art, many types of polymer foams were compressed for a variety of purposes. U.S. Patent Nos. 3,650,993; 3,740,283; 4,228,076; and 4,252,517 relate methods for densifying polyurethane foams, including open-cell foams, by compression to some desired thickness. U.S. Patent No. 4,656,906 relates a method for reticulating a polyurethane foam by compression. U.S. Patent No. 4,877,814 relates a method for making an open-cell polyethylene foam from a closed-cell polyethylene foam by compression. U.S. Patent No. 4,510,268 relates a method for improving the physical properties of an extruded, closed-cell polystyrene foam sheet by compression; such sheets are taught as useful for low temperature and cryogenic
15 insulation. U.S. Patent Nos. 3,863,908 and 5,114,656 relate methods for improving the properties of polystyrene bead foams by compression; the foams are described as useful in building, insulation, and packaging applications.

20 The present compressed, evacuated foam distinguishes the above prior art compressed foams in that it is both open cell and evacuated. The present foams are able to maintain a much greater degree of their insulating performance or heat resistance after compression than do open or closed cell foams at ambient pressure. Open or closed cell foams at ambient pressure can exhibit as much as a 70 to 75 percent increase in heat flow after compression compared to heat flow prior to or before compression at otherwise constant conditions. In contrast, preferred present compressed, evacuated foams can exhibit as little as a
25 15 percent increase in heat flow after compression and as little as a 5 percent increase in heat flow after compression when in most preferred compression levels.

30 The foam may take any physical configuration known in the art such as sheet or plank. The foam is particularly suited to be formed into a plank, desirably one having a cross-sectional area of 30 square centimeters (cm) or more and a minor dimension in cross-section (thickness) of 3/8 inch (0.95 cm) or more. Alternately, multiple foam sheets can be stacked to form a thicker foam body. Using multiple sheets allows for more rapid evacuation of gases from the interior of the evacuated panel.

35 The foam preferably contains an infrared attenuating agent (IAA) to enhance its insulating performance. The IAA is composed of a different substance than the polymer substrate of the foam in which it is incorporated. The IAA may absorb or reflect infrared radiation or both. Useful IAA include particulate flakes of metals such as aluminum, silver, and gold and carbonaceous substances such as carbon black, activated carbon black and graphite. Useful carbon blacks include thermal black, furnace black, acetylene black, and channel black. Preferred IAA are thermal black and graphite. The IAA preferably comprises between 1.0 and

25 weight percent and preferably between 2.0 and 20 weight percent and most preferably 3.0 to 10 weight percent based upon the weight of the polymer material.

5 Various additives may be incorporated in the compressed foam such as inorganic fillers, pigments, antioxidants, acid scavengers, ultraviolet absorbers, flame retardants, processing aids, and extrusion aids.

The present foam may be used to insulate a surface by applying to the surface an evacuated insulating panel employing the present foam. Such panels are useful in any conventional insulating applications such as roofing, buildings, refrigerators, controlled
10 temperature shipping containers, water heaters, refrigerated trucks and rooms.

The present foam is particularly useful as corestock in a hermetically-sealed evacuated panel. The panel may be formed as follows: a) the foam is placed inside a receptacle or enclosure such as a bag; b) the interior of the receptacle or enclosure and the foam are evacuated to a partial or near total vacuum; and c) the receptacle or enclosure is
15 sealed to be air tight or hermetically sealed. The interior of the evacuated or vacuum panel is evacuated to 10 torr or less, more preferably to 1 torr or less, and most preferably to 0.1 torr or less absolute pressure.

A useful evacuated panel employs as an enclosure formed of a laminate sheet of three or more layers. The outer layer comprises a scratch resistant material such as a polyester.
20 The middle layer comprises a barrier material such as aluminum, polyvinylidene chloride, and polyvinyl alcohol. The inner layer comprises a heat sealable material such as polyethylene or ethylene/acrylic acid copolymer.

To further enhance the long-term performance of the vacuum panel, the evacuated interior of the panel may be provided with a "getter" material. The getter material
25 adsorbs gases and/or vapors which seep or permeate into the vacuum panel over time. Conventional getter materials include metal and metal alloys of barium, aluminum, magnesium, calcium, iron, nickel, and vanadium. Teachings to suitable getter materials include but are not limited to those set forth in U.S. Patent Nos. 5,191,980; 5,312,606; 5,312,607; and
WO 93/25843.

30 Other types of useful getter materials include conventional dessicants, which are useful for adsorbing water vapor or moisture. Such materials are advantageously incorporated into the evacuated insulation panel in the form of a packet having a porous or permeable wrapper or receptacle containing the material therein. Useful materials include silica gel, activated alumina, aluminum-rich zeolites, calcium chloride, calcium oxide, and calcium sulfate.
35 A preferred material is calcium oxide.

Open-cell foams of virtually any average cell size can be employed in the present invention, but it is preferable to use a foam with an average size as small as possible to minimize foam thermal conductivity. Preferred foams are microcellular and have an average cell size of 70 micrometers or less, more preferably 1 to 30 micrometers, and most preferably 1

to 20 micrometers according to ASTM D3576-77. The smaller the average cell size, the smaller the potential foam thermal conductivity. The cell size or pore size (diameter) for the microcellular foams is determined according to ASTM D3576-77 except that measurement is
5 taken from an enlarged photograph obtained by scanning electron microscopy instead of measurement taken directly from the foam.

Extruded thermoplastic foams are generally prepared by heating a polymer material to form a plasticized or melt polymer material, incorporating therein a blowing agent to form a foamable gel, and extruding the gel through a die to form the foam product. Prior to
10 mixing with the blowing agent, the polymer material is heated to a temperature at or above its glass transition temperature or melting point. The blowing agent may be incorporated or mixed into the melt polymer material by any means known in the art such as with an extruder, mixer, or blender. The blowing agent is mixed with the melt polymer material at an elevated pressure sufficient to prevent substantial expansion of the melt polymer material and to
15 generally disperse the blowing agent homogeneously therein. The nucleating agent additive may be blended in the polymer melt or dry blended with the polymer material prior to plasticizing or melting. The foamable gel is typically cooled to a lower temperature to optimize or attain desired physical characteristics of the foam. The gel may be cooled in the extruder or other mixing device or in separate coolers. The gel is then extruded or conveyed through a die
20 of desired shape to a zone of reduced or lower pressure to expand to form the foam. The zone of lower pressure is at a pressure lower than that in which the foamable gel is maintained prior to extrusion through the die. The lower pressure may be superatmospheric or subatmospheric (evacuated or vacuum), but is preferably at an atmospheric level.

Optionally, after extrusion from the die, the expanding foam may be passed
25 between parallel plates or other forming devices to enhance skin quality and to ensure production of foam of desired dimension and specification. Such forming is not considered compression because it occurs while the foam is still expanding and takes place above the glass transition temperature of the constituent polymer material. Compression can occur after expansion of the foam is complete and the temperature of the foam has fallen below the glass
30 transition temperature of the constituent polymer material.

Compression may be accomplished by any means known in the art such as between opposing parallel plates or opposing rollers. Compression may be effected on-line as a part of a continuous manufacturing process or may be effected off-line on individual foam planks or sheets.

35 Preferred microcellular foams are extruded, microcellular alkenyl aromatic polymer foams. They are preferred because it is possible to make such foams to a relatively small average cell size, such as 10 micrometers and smaller. Extruded, open-cell microcellular alkenyl aromatic polymer foams having an open cell content of 70 percent or more and an average cell size of 70 micrometers or less may be made by the following process: a) heating an

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alkenyl aromatic polymer material to form a melt polymer material; b) incorporating into the melt polymer material a nucleating agent additive at from 0.1 to 5 parts by weight per hundred parts polymer material; c) incorporating into the melt polymer material at an elevated pressure to form a foamable gel a blowing agent of which 50 mole percent or more and preferably 70 mole percent or more is selected from the group consisting of 1,1-difluoroethane (HFC-152a), 1,1,1-trifluoroethane (HFC-143a), 1,1,1,2-tetrafluoro-ethane (HFC-134a), chlorodifluoromethane (HCFC-22), carbon dioxide (CO₂), and difluoromethane (HFC-32), and mixtures of the foregoing based upon the total number of moles of blowing agent, the blowing agent being present at 0.06 to 0.17 gram-moles or less and preferably 0.08 to 0.12 gram-moles or less per kilogram of polymer material; d) cooling the foamable gel to a foaming temperature sufficient to form a foam having 70 percent or more open cell content; and e) extruding the foamable gel through a die into a region of lower pressure to form the foam. Preferred foaming temperatures will vary from 118°C to 150°C and preferably 125°C to 135°C depending upon conditions.

Additional teachings to microcellular foams are seen in U.S. Patent No. 5,594,036.

Suitable alkenyl aromatic polymer materials include alkenyl aromatic homopolymers and copolymers of alkenyl aromatic compounds and copolymerizable ethylenically unsaturated comonomers. The alkenyl aromatic polymer material may further include minor proportions of non-alkenyl aromatic polymers. The alkenyl aromatic polymer material may be comprised solely of one or more alkenyl aromatic homopolymers, one or more alkenyl aromatic copolymers, a blend of one or more of each of alkenyl aromatic homopolymers and copolymers, or blends of any of the foregoing with a non-alkenyl aromatic polymer. Regardless of composition, the alkenyl aromatic polymer material comprises greater than 50 and preferably greater than 70 weight percent alkenyl aromatic monomeric units. Most preferably, the alkenyl aromatic polymer material is comprised entirely of alkenyl aromatic monomeric units.

Suitable alkenyl aromatic polymers include those derived from alkenyl aromatic compounds such as styrene, alphas-methylstyrene, ethylstyrene, vinyl benzene, vinyl toluene, chlorostyrene, and bromostyrene. A preferred alkenyl aromatic polymer is polystyrene. Minor amounts of monoethylenically unsaturated compounds such as C₂₋₆ alkyl acids and esters, ionomeric derivatives, and C₄₋₆ dienes may be copolymerized with alkenyl aromatic compounds. Examples of copolymerizable compounds include acrylic acid, methacrylic acid, ethacrylic acid, maleic acid, itaconic acid, acrylonitrile, maleic anhydride, methyl acrylate, ethyl acrylate, isobutyl acrylate, n-butyl acrylate, methyl methacrylate, vinyl acetate and butadiene. Preferred foams comprise substantially (that is, greater than 95 percent by weight polystyrene) and most preferably entirely of polystyrene.

Open-cell microcellular alkenyl aromatic polymer foams are particularly suited to be formed into a sheet or plank. The foam is particularly suited to be extruded into a plank, desirably one having a cross-sectional area of 30 square centimeters (cm) or more and a minor dimension in cross-section (thickness) of 3/8 inch (0.95 cm) or more. Alternately, multiple foam sheets can be stacked to form a thicker corestock. Using multiple sheets allow more rapid evacuation of gases from the interior of the evacuated panel.

Open-cell polyurethane and polyisocyanurate foams can be made by reacting two preformulated components, commonly called the A-component and the B-component. The blowing agent may be dispersed in either the isocyanate or the polyol or both.

Suitable polyisocyanates include diisocyanates such as m-phenylene diisocyanate, toluene-2,4-diisocyanate, toluene-2,6-diisocyanate, mixtures of 2,4- and 2,6-toluene diisocyanate, hexamethylene-1,6-diisocyanate, tetramethylene-1,4-diisocyanate, cyclohexane-1,4-diisocyanate, hexahydrotoluene 2,4- and 2,6-diisocyanate, naphthalene-1,5-diisocyanate, diphenyl methane-4,4'-diisocyanate, 4,4'-diphenylenediisocyanate, 3,3'-dimethoxy-4,4'-biphenyldiisocyanate, 3,3'-dimethyl-4,4'-biphenyldiisocyanate, and 3,3'-dimethyldiphenylmethane-4,4'-diisocyanate; the triisocyanates such as 4,4',4''-triphenylmethane-triisocyanate, polymethylenepolyphenyl isocyanate, toluene-2,4,6-triisocyanate; and the tetraisocyanates such as 4,4'-dimethyldiphenylmethane-2,2',5,5'-tetraisocyanate.

Suitable polyols include: ethylene glycol; propylene glycol-(1,2) and -(1,3); butylene glycol-(1,4) and -(2,3); hexane diol-(1,6); octane diol-(1,8); neopentyl glycol; 1,4-bishydroxymethyl cyclohexane; 2-methyl-1,3-propane diol; glycerin; trimethylolpropane; trimethylolethane; hexane triol-(1,2,6); butane triol-(1,2,4); pentaerythritol; quinitol; mannitol; sorbitol; formitol; a-methyl-glucoside; diethylene glycol; triethylene glycol; tetraethylene glycol and higher polyethylene glycols; dipropylene glycol and higher polypropylene glycols as well as dibutylene glycol and higher polybutylene glycols. Suitable polyols further include oxyalkylene glycols, such as diethylene glycol, dipropylene glycol, triethylene glycol, tripropylene glycol, tetraethylene glycol, tetrapropylene glycol, trimethylene glycol and tetramethylene glycol.

Polyurethane foams can be prepared by reacting the polyol and the isocyanate on a 0.7:1 to 1.1:1 equivalent basis. The polyisocyanurate foams of the invention are advantageously prepared by reacting the polyisocyanate with a minor amount of polyol to provide 0.10 to 0.70 hydroxyl equivalents of polyol per equivalent of polyisocyanate. Useful polyurethanes and polyisocyanurates and processes for making them are seen in U.S. Patent Nos. 3,580,869; 4,795,763; 5,288,766; 5,334,624; and 5,346,928. Open-cell polyurethane foams with average cell sizes as little as 50 micrometers have been produced commercially for use in evacuated panels.

Another useful foam as a corestock are microporous thermoplastic foams. Microporous thermoplastic foams can be formed by phase separation, by microemulsions, or by use of supercritical fluids such as seen in U. S. Patent Nos. 4,673,695; 4,473,665; 5,037,859; 5,158,986; and 5,334,356. Useful pore sizes (corresponding to cell sizes) are the same as those described for the microcellular foams above.

Further surprisingly, certain foams have been found useful in fabrication applications at atmospheric and non-evacuated pressures. The foams have 1 to 70 micrometer cell size prior to compression, 25 to 100 kg/m³ density prior to compression, and 70 percent or more open cell content prior to compression. The foam is readily formable and compressible to a variety of configurations and shapes. The fabricated foam maintains the deformed or compressed configuration while exhibiting 5 percent or less recovery on a thickness or volume basis after release of the compressing or deforming stress.

The fabricable foam has superior formability and compressibility compared to prior art foams of larger average cell size. The smaller average cell size of the present foam provides cell walls of smaller average thickness, which result in a foam matrix which is more readily deformable yet not so small in cell wall thickness as to be brittle and collapsible.

The fabricable foam is more formable and compressible than prior art closed-cell foams because the open-cell structure of the present foam affords faster cell gas transfer out of the foam during deformation. The faster cell gas transfer decreases resistance to deformation and minimizes foam recovery upon release of mechanical stress.

The fabricable foam can deform upon application of mechanical stress without substantial fracture or collapse as observed in polyisocyanurate and rigid polyurethane foams and without exhibiting substantial resiliency or recovery upon release of mechanical stress as observed in polyolefin foams or flexible polyurethane foams. Alkenyl aromatic polymers in the present fabricable foams are superior to polyisocyanurate or rigid polyurethane polymers because they can deform to a substantial degree without fracture or collapse and are superior to polyolefins because they can deform without exhibiting substantial resiliency or recovery.

The following are examples of the present invention, and are not to be construed as limiting. Unless otherwise indicated, all percentages, parts, or proportions are by weight based upon polymer weight.

Control Examples 1-3 and Examples 1A-3A

Open-cell foams were measured for permitted heat flow rate before and after compression at a vacuum of 0.2 torr (examples). Corresponding foams at atmospheric pressure were likewise measured for heat resistance before and after compression (control examples).

Control Examples 1-2 and Examples 1A-2A were each extruded microcellular polystyrene foams containing 7 parts per hundred (pph) graphite based upon the weight of the polymer as an infrared attenuating additive. Control Example 3 and Example 3A were each a rigid polyurethane foam which did not contain an infrared attenuating additive. The foams of

the control examples had a foam cell gas pressure of 760 torr and the foams of the examples had a foam cell gas pressure of 0.2 torr.

As seen in Table 1, the foams of the examples retained all or most of their original
5 levels of heat resistance (inversely related to heat flow rate shown in Table 1) after compression. In contrast, the foams of the control examples exhibited markedly lower levels of heat resistance after compression. The results demonstrate the importance of foam evacuation to the present invention.

Comparative Examples 4A, 4B, 5A, 5B, 6A, and 6B

10 Closed-cell foams were measured for permitted heat flow rate before and after compression at a vacuum of 0.2 torr and at atmospheric pressure (760 torr).

As seen in Table 2, the foams of the comparative examples exhibited markedly lower levels of heat resistance after compression than Examples 1A-3A. The results demonstrate the criticality of open cell content to the present invention.

15 Example 7

A fabricable foam was impressed with the surfaces of several door keys and coins. The foam was examined for the quality of impressions therein.

The foam was made with the second extrusion system of Example 1 with 7.1 pph HFC-134a, 1.0 pph carbon dioxide, 7 pph natural graphite No. FP248 (Graphite Sales, Inc.). The
20 polymer was a polystyrene of 135,000 weight average molecular weight according to SEC. The cell size was 3.0 micron, the density was 2.7 pounds per cubic foot (pcf), and the open cell content was 100 percent.

The surface features of the keys and the coins, including letters and numerals, were readily discernible in the surface of the foam upon the removal of same. The impressions
25 were permanently set in the foam.

Example 8

A fabricable foam was fabricated by simple compression against an existing molding trim. The compressed foam resembled baseboard trim useful for molding around doors, floors, or ceilings. The foam retained substantial deformation without substantial
30 collapse or recovery. Prior to compression, the foam had a density of 2.7 pcf (43 kg/m³), a cell size of 30 micrometers, and an open cell content of greater than 99 percent.

While embodiments of the compressed foam and the evacuated insulation panel of the present invention have been shown with regard to specific details, it will be appreciated that depending upon the manufacturing process and the manufacturer's desires, the present
35 invention may be modified by various changes while still being fairly within the scope of the novel teachings and principles herein set forth.

TABLE 1
Effect of Foam Compression on Heat Flow Rate
Through Foam Samples Under Vacuum and at Atmospheric Pressure

Sample Number	Foam Cell Gas Pressure	Initial Open Cell (percent)	Final Open Cell (percent)	Initial Thickness (inch (cm))	Final Thickness (inch (cm))	Level of Compression (percent)	Initial Heat Flow Rate ¹ (BTU/ft ² -hr-°F) ((W/m ² -°K))	Final Heat Flow Rate ² (BTU/ft ² -hr-°F) ((W/m ² -°K))	Change in Heat Flow Upon Compression (percent)
1*	760 torr	>99	>99	1.11 (2.82)	0.74 (1.90)	33	0.209 (11.56)	0.293 (16.20)	+40
1A	0.2 torr	>99	>99	1.11 (2.82)	0.74 (1.90)	33	0.041 (2.27)	0.045 (2.49)	+9
2*	760 torr	>99	>99	1.00 (2.54)	0.62 (1.60)	38	0.233 (12.88)	0.312 (17.25)	+34
2A	0.2 torr	>99	>99	0.66 (1.70)	0.37 (0.94)	44	0.077 (4.26)	0.080 (4.42)	+4
3*	760 torr	>99	>99	1.07 (2.72)	0.69 (1.80)	36	0.251 (13.88)	0.344 (19.02)	+37
3A	0.2 torr	>99	>99	1.07 (2.72)	0.69 (1.80)	36	0.139 (7.69)	0.138 (7.63)	+0

* Not an example of the present invention

Sample Number 1 and 1A. Open cell polystyrene foam, 7 pph graphite, 2.7 pounds per cubic foot (pcf) (43.2 kilograms per cubic meter (kg/cm³)) initial density

Sample Number 2 and 2A. Open cell polystyrene foam, 7 pph graphite, 4.1 pcf (65.6 kg/cm³) initial density

Sample Number 3 and 3A. Open cell rigid polyurethane foam, 5.2 pcf (83.2 kg/cm³) initial density

¹ Initial heat flow rate per degree temperature; also corresponds to thermal conductivity divided by initial thickness

² Final heat flow rate per degree temperature; also corresponds to thermal conductivity divided by final thickness

TABLE 2
Effect of Foam Compression on Heat Flow Rate
Through Foam Samples Under Vacuum and at Atmospheric Pressure

Sample Number	Foam Cell Gas Pressure	Initial Open Cell (percent)	Final Open Cell (percent)	Initial Thickness (inch (cm))	Final Thickness (inch (cm))	Level of Compression (percent)	Initial Heat Flow Rate ¹ (BTU/ft ² -hr-°F) ((W/m ² -°K))	Final Heat Flow Rate ² (BTU/ft ² -hr-°F) ((W/m ² -°K))	Change in Heat Flow Upon Compression (percent)
4A*	760 torr	11	36	0.94 (2.39)	0.44 (1.12)	53	0.2692 (14.89)	0.4827 (26.69)	+ 43
4B*	0.2 torr	11	36	0.94 (2.39)	0.44 (1.12)	53	0.2668 (14.75)	0.3238 (17.91)	+ 22
5A*	760 torr	3	4	0.99 (2.51)	0.74 (1.88)	26	0.1939 (10.72)	0.2417 (13.37)	+ 25
5B*	0.2 torr	3	4	1.00 (2.54)	0.76 (1.93)	24	0.1930 (10.67)	0.2310 (12.77)	+ 20
6A*	760 torr	3	5	0.63 (1.60)	0.44 (1.12)	30	0.3047 (16.85)	0.4066 (22.49)	+ 33
6B*	0.2 torr	3	5	0.63 (1.60)	0.44 (1.12)	30	0.3360 (18.58)	0.4511 (24.95)	+ 34

* Not an example of the present invention

Sample Number 4A and 4B. Molded polystyrene bead foam; initial density of 1.09 pounds per cubic foot (pcf) (17.4 kilograms per cubic meter (kg/cm³))

Sample Number 5A and 5B. Extruded polystyrene foam; initial density of 1.68 pcf (26.9 kg/cm³)

Sample Number 6A and 6B. Extruded polystyrene foam; 7 pph carbon black, initial density of 1.68 pcf (26.9 kg/cm³)

¹ Initial heat flow rate per degree temperature; also corresponds to thermal conductivity divided by initial thickness

² Final heat flow rate per degree temperature; also corresponds to thermal conductivity divided by final thickness

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CLAIMS:

1. A method for enhancing the insulating capability of a polymer foam on a per-unit thickness basis, the method comprising the following steps:
 - 5 a) providing an open cell polymer foam of 70 percent or more open cell content and having a density of 16 to 250 kilograms per cubic meter;
 - b) compressing the foam to a thickness of 30 to 90 percent of the initial thickness of the foam prior to
10 compression; and
 - c) evacuating the foam to an absolute cell gas pressure of 10 torr or less in its open cells.
2. The method of claim 1, wherein the foam is evacuated to an internal absolute cell gas pressure of 1
15 torr or less in its open cells.
3. The method of claim 1 or 2, wherein the foam is evacuated to an internal absolute cell gas pressure of 0.1 torr or less in its open cells.
4. The method of any one of claims 1 to 3, wherein
20 the foam has an average cell size of 1 to 70 micrometers prior to compression.
5. The method of any one of claims 1 to 3, wherein the foam has an average cell size of 1 to 30 micrometers prior to compression.
- 25 6. The method of any one of claims 1 to 3, wherein the foam has an average cell size of 5 to 10 micrometers prior to compression.

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7. The method of any one of claims 1 to 6, wherein the foam has an open cell content of 90 percent or more.

8. The method of any one of claims 1 to 6, wherein the foam has an open cell content of 95 percent or more.

5 9. The method of any one of claims 1 to 8, wherein the foam is compressed to 40 to 70 percent of the initial thickness.

10. The method of any one of claims 1 to 8, wherein the foam is compressed to 50 to 60 percent of the initial
10 thickness.

11. The method of any one of claims 1 to 10, wherein the foam is an alkenyl aromatic polymer foam, the foam having an alkenyl aromatic polymer material having 50 percent or more by weight of alkenyl aromatic monomeric
15 units.

12. The method of any one of claims 1 to 10, wherein the foam is an alkenyl aromatic polymer foam, the foam having alkenyl aromatic polymer material having 70 percent or more by weight of alkenyl aromatic monomeric units.

20 13. The method of any one of claims 1 to 10, wherein the foam is a polystyrene foam.

14. The method of any one of claims 1 to 13, wherein the foam is an extruded foam.

15. The method of any one of claims 1 to 10, wherein
25 the foam is selected from the group consisting of a polyisocyanurate foam and a polyurethane foam.

16. A foam obtained according to a method according to any one of claims 1 to 15.

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17. An evacuated foam insulation panel, the panel being of a foam according to claim 16 and a receptacle capable of enclosing the foam and being hermetically sealed, the foam being situated within the receptacle.

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