

PROCESS FOR PROCESSING EXPANDABLE POLYMER PARTICLES
AND FOAM ARTICLE THEREOF

5 BACKGROUND OF THE INVENTION

1. Field of the invention

 The invention relates to a process for
processing expandable polymer particles, e.g.
10 expandable polystyrene (EPS) particles. More
particularly, the invention relates to a process for
processing expandable polymer particles that contain
an organic or an inorganic blowing agent or mixtures
thereof in varying amounts. The particles are first
15 over pressurized with gas; pre-expanded and dried;
and then fed without maturing into a molding machine
to form a foam article.

2. Background Art

20 Polymer foam articles molded from expandable
polymer particles are well known. According to
conventional practice, the conversion from
expandable polymer particles to a molded foam
article generally occurs in three steps: pre-
25 expansion, maturing, and molding. The most commonly
known and used expandable polymer particles are
expandable polystyrene particles referred to as EPS.
These expandable particles are generally made as
solid, relatively "high-density" polystyrene beads
30 of a relatively small size, e.g. beads having a
diameter of from about 0.2 to 4.0 millimeters and a
bulk (packing) density of about 600 kg/m³.
Typically, these polystyrene beads are impregnated
with a blowing agent, e.g. hydrocarbon, i.e.
35 pentane, etc., and then heated with saturated steam
to produce "pre-expanded" polystyrene particles,

5 i.e. larger particles of lower density. If
hydrocarbon is used as the blowing agent, the amount
generally ranges from about 3.0% by weight to about
7.0% by weight based on the weight of the
polystyrene. The blowing agent boils below the
10 softening point of the polystyrene and causes the
beads to expand when they are heated with the
saturated steam, resulting in the particles being
pre-expanded to a lower bulk density of about 8 to
80 kg/m³.

15 The pre-expanded particles, commonly referred to
as "pre-puff" or "pre-foam", must be aged for at
least about an hour, and generally about 8 to 24
hours, to allow the particles to mature before they
can be molded into a foam article. During the
20 maturing process, air permeates the particles, and
the internal pressure of the particles, which is
initially lower than atmospheric, gradually
approaches atmospheric pressure. At the same time,
the external and the internal moisture in the
25 particles evaporate. If pentane is used as the
blowing agent, the condensation of pentane creates
an under pressure compared to atmospheric pressure.
During maturing, this condition is equilibrated and
is necessary for good molding.

30 For the maturing process, it is known that
there is a relatively narrow window (e.g. a few
hours) of the optimum aging (maturing) time that
will yield the highest quality moldings at the
minimum molding cycle times. The optimum maturing
35 time is determined by trial and error and is a
complex function of such variables as bead size,

5 blowing agent level, bulk density, pre-expansion
conditions and maturing conditions (e.g.
temperature, ventilation, etc.).

For the maturing process, the pre-expanded
particles are generally stored in large vented bags.
10 In general, a substantial amount of storage space is
required, and scheduling and inventory control of
the bags are cumbersome. In addition, the maturing
process takes time. Also, if pentane is used as the
blowing agent, some pentane vapor is released from
15 the bags. It is difficult to capture and destroy
this released pentane vapor since the air volume is
very large and the relative pentane content is low.
This presents an environmental and safety hazard,
and, requires proper ventilation in order to avoid
20 explosive air-hydrocarbon mixtures. A further
disadvantage with the conventional practice of
maturing or aging the pre-expanded particles prior
to molding is the reduction in the flexibility of
the plant. That is, the pre-expanded particles
25 require that they be used within two to 24 hours
after the maturing process. Therefore, the manpower
and molding equipment in the plant need to be
readily available at this time.

It would be desirable to have a process that
30 does not require a maturing step whereby pre-
expanded polymer particles may be molded
immediately after the particles are pre-expanded.

There have been some developments that do not
require storage and maturing of an intermediate pre-
35 expanded product.

5 Collum et al., U.S. Patent No. 5,271,886
assigned to Arco Chemical Technology, L.P. and
issued on December 21, 1993, uses a moving stream
that contains carbon dioxide-impregnated polymer
particles and a heating fluid. A pre-expansion
10 unit provides a heated and thermally insulated
expanding pathway through which carbon-dioxide
impregnated polymer particles and the moving heating
fluid flow. The moving stream of steam containing
the pre-expanded polymer particles exits from the
15 pre-expansion unit and is directed into a molding
machine. The moving heating fluid is charged to the
pre-expansion unit at a temperature from 250° to
500°F, and preferably, super-heated steam at a
temperature from 350° to 500°F.

20 A further development that eliminates the
maturing process for pre-expanded particles prior to
the molding step is disclosed in A. P. August et
al., U.S. Patent No. 6,399,665 B1 issued on June 4,
2002. This patent discloses that the pre-expansion
25 of EPS particles has long been carried out with heat
of condensation from steam that permeates the beads
and deposits water droplets within expanding cells
of the beads. This invention uses dry heated gas,
such as air, to pre-expand the raw EPS beads through
30 conduction only. The outer layer of the beads are
first heated by the hot air and the heat penetrates
conductively inwardly thereby forming a more pre-
expanded structure (with thinner cell walls) on the
peripheral surface of the beads and a less expanded
35 structure (with thicker cell walls) at the interior
of the beads. The pre-expanded beads contain a

5 higher percent content of blowing agent since the
blowing agent is locked within the interior cells of
each bead. The resultant pre-expanded beads are dry
and can be used immediately in molding of EPS foam
articles due to excellent flow characteristics and
10 excellent expansion capability (due to high residual
pentane content). These resultant beads differ from
those pre-expanded with steam in that thermal
conduction enlarges peripheral cells more than
interior cells in each bead, while steam acts by
15 convection to permeate each bead (and condense
within each cell), thereby expanding both peripheral
and interior cells to substantially the same degree.

Detailed information explaining the technical
reasons for maturing the impregnated particles,
20 particularly those for conventional EPS containing
pentane as the blowing agent, are given in the
background section of the above-discussed U.S.
Patent No. 6,399,665. The maturing period generally
allows the internal pentane pressure within the
25 cells and the atmospheric pressure to reach a steady
state equilibrium as well as to dry the pre-expanded
beads sufficiently so that condensed water vapor on
the surfaces of the beads does not cause the beads
to agglomerate into lumps, which may not easily pass
30 through the filling valve used in filling the mold
or may not flow into corners and narrow spaces of
the mold itself. This aging period also permits
some of the water droplets (from condensed steam)
that are inside the cells to escape through the cell
35 walls thus drying the inside of the foamed beads.
Without inside drying, the trapped water droplets

5 sometime induce local non-uniformities, e.g. holes
in the molded article because each droplet requires
longer heating to vaporize it before heating and
expansion of the surrounding cell can progress.
However, care must be taken that the aging period is
10 not too long as too much of the remaining blowing
agent (e.g. pentane) may be lost by diffusion out of
the cells of the pre-expanded beads, resulting in
pre-expanded beads that no longer have the ability
to expand further when they are heated during
15 molding. When the beads do not expand sufficiently
during molding, the molded foam articles tend to be
poorly fused, and often crumble into pieces or leak
their contents i.e. coffee in the case of coffee
cups. Thus, for many years, proper aging of pre-
20 expanded beads has been a delicate balance between a
sufficiently long time needed to dry the condensed
steam introduced during pre-expansion, and a
sufficiently short time to retain an adequate amount
of blowing agent, e.g. pentane within the pre-
25 expanded beads. Aging not only allows some of the
pentane and condensed water vapor to escape through
the cell walls to the surrounding atmosphere, but
also allows air to permeate back into the vacuum
left inside the cells following expansion so that
30 the particles do not collapse during molding.

As stated hereinabove, the inventions of U.S.
Patent Nos. 5,271,886 and 6,399,665 are directed to
a process for processing expandable polymer
particles that require no maturing or aging of the
35 particles after the pre-expansion step and before
the molding step. U.S. Patent No. 5,271,886

5 pertains to particles that contain carbon dioxide
as a blowing agent, and U.S. Patent No. 6,399,665
pertains to particles that contain pentane as a
blowing agent.

10 A further example of expandable polymer
particles with carbon dioxide as a blowing agent is
Meyer et al. U.S. Patent No. 4,911,869. This patent
teaches that because of the rapidity with which the
carbon dioxide diffuses out of the polymer
15 particles, it is necessary to first pre-expand the
particles and then re-impregnate the particles with
the same or a different gas just prior to molding.
The above discussed U.S. Patent No. 5,271,886 gets
around this problem by expanding the beads to their
final density as the beads are in route to the
20 molding operation without maturing and without re-
inflating the pre-puff prior to molding.

 The use of carbon dioxide gas as a blowing agent
in expandable polymer particles is also disclosed in
Meyer et al. U.S. Patent No. 5,049,328. This patent
25 combines the steps of impregnation, purification,
and foaming into a single process, which overcomes
the rapid diffusion of the carbon dioxide gas out of
the particle. Again, the above U.S. Patent No.
5,271,886 gets around this problem by expanding the
30 beads to their final density as the beads are in
route to the molding operation without maturing and
without re-inflating the pre-puff prior to molding.

 There is still a need in the art to provide a
process which eliminates the maturing step generally
35 associated with conventional expandable polymer
particles regardless of the type and/or amount of

5 blowing agent in the particles after the pre-
expansion process so that the pre-expanded particles
can be immediately fed into the mold and "good"
quality foam articles are formed.

10 There is a further need to provide a process
that may eliminate re-impregnation prior to molding.

SUMMARY OF THE INVENTION

15 The invention has met these needs. The
invention provides a process for processing
expandable polymer particles that eliminates the
need for a maturing step between the pre-expansion
and molding steps. If the expandable polymer
particles contain an inorganic blowing agent, e.g.
carbon dioxide or water, or contain a very low
20 amount of organic blowing agent, e.g. about 1.0 to
about 3.0% by weight pentane, the invention allows
the particles to be immediately transferred from a
pre-expansion step to a molding step.

25 The invention provides a process for processing
expandable polymer particles into a foam article.
The process comprises the steps of: a) subjecting
expandable polymer particles to a pressurization
step where a relatively high pressure is established
in the particles; b) pre-expanding the particles so
30 as to lower the density of the particles while
retaining a sufficient positive pressure inside the
particles and drying the pre-expanded particles
while still maintaining a sufficient pressure in the
particles; and c) immediately molding the pre-
35 expanded particles to form a molded foam article.

5 More specifically, the process of the invention comprises the steps of: a) pressurizing the expandable polymer particles with compressed gas at a pressure and temperature to create a relatively high gas pressure inside the particles; b) using at
10 least the gas pressure in the particles created in the pressurization step a), pre-expanding the particles with a heating medium while maintaining a sufficient positive pressure in the particles which pressure is above atmospheric pressure and directing
15 a flow of hot dry air for a sufficient time onto the particles to dry the particles while maintaining a sufficient positive pressure in the particles which pressure is above atmospheric pressure; and c)
 immediately molding the particles into a foam
20 article using at least the residual gas pressure in the particles.

 Expandable polymer particles may have a bulk density of about 600 kg/m^3 and may contain an organic blowing agent, e.g. hydrocarbon, i.e. pentane,
25 isopentane, and mixtures thereof and/or may contain an inorganic blowing agent, e.g. water, air, nitrogen, carbon dioxide, argon, neon and mixtures thereof. The amount of blowing agent in the expandable particles may range from about 0 weight
30 percent to about 20 weight percent. The expandable particles may be "pre-nucleated", i.e. particles that have a previously established cell or pore structure where the apparent density of the expandable particles has been slightly decreased
35 thus resulting in the volume being slightly increased. Or the expandable particles may be "non-

5 -nucleated", i.e. particles that have voids and no
previously established cell or pore structure.

 The invention may find particular application
for processing expandable polystyrene particles that
contain an organic blowing agent, e.g. pentane, in
10 an amount less than about 3% by weight, or that
contain an inorganic blowing agent such as water,
carbon dioxide, air, or nitrogen, which inorganic
blowing agent, e.g. carbon dioxide, as discussed
hereinabove, generally dissipates quickly out of the
15 cells and therefore out of the particles. In this
instance, the pressurization step a) and the
pressure of the heating medium applied to the
particles in the pre-expansion step b) assure that
the particles have sufficient pressure for the
20 required expansion in the molding process to
adequately fuse the particles together for the
production of foam articles.

 In the pressurization step, the expandable
particles are over-pressurized with gas at a
25 pressure ranging from about 500kPa to about 8000kPa
and at a temperature ranging from about -20°C to
about 130°C for about 15 minutes to about 7200
minutes (5 days). The result is that pressurized
gas is created and remains in the particles, i.e. in
30 the voids or in the cells of the particles. These
pressurized particles are then transferred to the
pre-expansion unit.

 The pre-expansion unit contains a heating medium
for pre-expanding the particles. The heating medium
35 may be supplied at a pressure ranging from about
50kPa to about 200kPa and at a temperature ranging

5 from about 100°C to about 130°C. In general, the pressure in the pre-expander will be above atmospheric pressure and below the pressure inside the particles upon the particles exiting from the pressurization unit. This creates a pressure
10 differential between the pressure in the particles as a result of the pressurization step and the pressure in the pre-expansion unit. The heating medium will cause the particles to soften, and the pressure differential in the particles will cause
15 the particles to expand.

Within the pressurized atmosphere of the pre-expansion unit the particles may be subjected to a drying process, e.g. an air-drying process, at the pressure existing in the pre-expansion unit. That
20 is, after the particles are pre-expanded a stream of hot dry air may be transported through the pre-expansion unit and onto the particles.

Alternatively, the drying of the particles can be done in a separate pressurized compartment of the pre-expansion unit or in a separate pressurization
25 unit.

Preferably, the particles are transferred from the pre-expansion unit directly into the molding machine. However, depending on the production rate
30 of the plant, it may be necessary to transfer the particles to a holding vessel until the molding machine is available. The holding vessel may be a vacuum tight pressure silo that maintains the pressure in the particles, or the holding vessel may
35 have a small net airflow.

5 As stated hereinabove, the particles are transferred from the pre-expansion unit or from the pressure silo and to the molding machine. The pressure differential between the outside of the particles and the environment will be zero but the
10 pressure inside the particles will be above atmospheric. As the pressurized particles enter the molding machine, the partial pressure of the gas inside the particles is greater than the air pressure inside the molding machine. This will
15 allow the particles to further expand and fuse together when the particles are heated in the molding machine.

 Since in the pre-expansion unit, the particles have a sufficient pressure and the particles are
20 dried, the particles can be fed directly to the molding machine without maturing the particles.

 Suitable gases supplied to the pressurization unit for developing a relatively high gas pressure therein include air, carbon dioxide, nitrogen, and
25 mixtures thereof. Preferably, the gas is selected from the group consisting of air, carbon dioxide and mixtures thereof.

 It is therefore an object of the present invention to provide a process for processing
30 expandable polymer particles that applies a relatively high gas pressure to the particles and includes maintaining pressure in the particles thereby allowing the particles to be directly transferred from the pre-expansion unit to a molding
35 machine without a maturing step.

5 It is a further object of the present invention
to provide a process for processing expandable
polymer beads into a molded foam article that over-
pressurizes the particles, pre-expands and dries the
pressurized particles, and immediately molds the
10 pressurized particles to form a foam article.

 A still further object of the present invention
is to provide a process for processing expandable
polymer particles regardless of the amount and/or
type of blowing agent in the expandable polymer
15 particles that allows the particles to be molded
immediately after the particles are pre-expanded.

 And a still further object of the present
invention is to over-pressurize the expandable
particles so that a sufficient amount of pressure
20 remains in the particles for pre-expansion and
molding.

 These and other objects of the invention will
be better appreciated and understood when the
following description is read along with the
25 accompanying drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

 FIGURE 1 is a schematic of the process of the
prior art where conventional expandable polystyrene
30 (EPS) particles are pre-expanded, matured, and
molded.

 FIGURE 2 is a schematic of the process of the
invention where expandable polymer particles are
pressurized, pre-expanded and dried, and then
35 molded.

5 DETAILED DESCRIPTION OF THE INVENTION

Figure 1 is a schematic of a conventional process for processing conventional expandable polystyrene particles. Expandable polystyrene particles 8 are fed to the pre-expansion unit 10 where steam is applied to the particles to lower the density of the particles. As discussed hereinabove, the lower density particles are transferred from the pre-expansion unit 10 into large vented bags for the maturing process 12, and are then transferred to the molding machine 14 to produce a finished foam article 16. In the particles of the prior art, if the blowing agent, e.g. pentane is too low, the particles generally are placed into a pressure tank (not shown) before entering and/or after exiting the pre-expansion unit 10.

Figure 2 is a schematic of the process of the invention. The process of the invention involves over-pressurizing expandable polymer particles in a pressure vessel 18 for a pressurization step, then transferring the polymer particles to a pre-expansion unit 20 for the pre-expansion and drying steps, and then immediately to a molding machine 22 for the molding step to produce a finished foam article 24.

30 "Particles" as used herein designate beads, pellets, or comminuted pieces.

Polymers suitable for use in the process of the invention are thermoplastic polymers. These polymers include, but are not limited to, polystyrene, styrene copolymers, e.g. styrenic/maleic anhydride copolymers, polyphenylene

5 oxide, polystyrene-polyphenylene oxide blends,
polyoxymethylene, poly(-methyl methacrylate), methyl
methacrylate copolymers, polyethylene,
polypropylene, ethylene-propylene copolymers,
polyvinyl chloride, polycarbonate, polyethylene
10 terephthalate, crosslinked variations thereof,
rubber-modified versions thereof, blends thereof,
and interpenetrating networks thereof, e.g.
polyethylene and polymerized vinyl aromatic resins,
such as polystyrene.

15 While a preferred embodiment will be discussed
with reference to expandable polystyrene (EPS)
particles, as indicated in the preceding paragraph,
other expandable polymer particles, e.g. expandable
polyethylene (EPE), expandable polypropylene (EPP),
20 styrenic copolymers, etc. may be employed in
carrying out the invention.

The polymer particles of the invention are
expandable in that they generally contain a blowing
agent. The blowing agent may be incorporated into
25 the particles during forming of the particles. The
blowing agent may be organic or inorganic or
mixtures thereof. Organic blowing agents may be
hydrocarbon, e.g. n-pentane (normal pentane),
butane, isopentane, and mixtures of pentane, and
30 preferably, n-pentane and mixtures of pentane.
Inorganic blowing agents may be carbon dioxide,
nitrogen, air, water, and other pneumatogens and
mixtures thereof.

The blowing agent, particularly for expandable
35 polystyrene particles, will generally range from
about 0.1% to about 8% by weight based on the weight

5 of the polymer. Incorporation of the blowing agent into the particles may occur when the particles are formed. This may occur in a one step suspension process or the blowing agent may be impregnated into the particles after the particles are formed in what
10 is generally referred to as a two-step suspension process.

If little or no blowing agent exists in the particles, then the gas pressure applied to the particles in the pressurization step of the
15 invention will provide sufficient pressure in the particles and pressure is maintained for the pre-expansion and molding steps. As an example, if 40 bar of pressure is applied to the particles for about three (3) hours in the pressurization step,
20 the pressure in the beads may be about 22.5 bar.

A process had been developed that decreases or eliminates the fast diffusion rate of inorganic blowing agents, such as carbon dioxide and/or water. This process maybe referred to as "pre-nucleation".
25 "Pre-nucleation" of the particles is achieved by slightly expanding the particles to a density that is not more than 3 times lower than the original density of the particles. The particles used in this pre-nucleation process may contain the
30 inorganic blowing agents discussed herein above, i.e. carbon dioxide, nitrogen, air, water, and other pneumatogens and mixtures thereof, or may contain water and/or a small amount, e.g. about 2 weight percent or less, of an organic blowing agent, e.g.
35 hydrocarbon liquid, e.g. pentane and/or mixtures thereof. In "pre-nucleation", the initial nuclei of

5 the cells are formed in the particles. The nuclei
of the cells are then used to subsequently further
expand the particles with pressurized gas to the
final bulk density of commercial interest.

10 The process for preparing pre-nucleated
particles, i.e. particles that already have a
certain cell structure is disclosed in the following
two patent documents.

15 WO 00/15703 (U.S. Patent No. 6,538,042 B1 issued
on March 25, 2003) relates to porous polyvinylarene
particles. The unexpanded particles are slightly
expanded to create porous particles having a certain
cell structure and an apparent density ranging
between 200 and 600 kg/m³ and containing less than
2% by weight of an organic blowing agent. These
20 porous particles have a volume increase that is from
about 1.5 to less than 3 times compared to the
volume of the unexpanded particles.

25 WO 00/15704 (U.S. Patent No. 6,455,599 B1 issued
on September 24, 2002) relates to a process for the
preparation of expanded porous particles by
impregnating particles having a density ranging from
200 to 600 kg/m³ with an inorganic gas and expanding
the particles to a density that is not more than 3
times lower than the original density of the
30 unexpanded particles.

A process for preparing expandable polymer
particles that contain voids in the solid particles
is disclosed in the following patent document.

35 WO 00/15702 (U.S. Patent No. 6,573,306 B1
issued on June 3, 2003) relates to a process for the
preparation of expandable polyvinylarene particles

5 in which solid polyvinylarene particles containing
voids are impregnated by exposing the solid
particles to an inorganic compound selected from the
group consisting of N₂ and/or O₂ containing gas and a
temperature below 95°C and at a pressure of 100 to
10 2,000kPa gauge to maintain the structure and
properties of the voids in the solid particles. The
inorganic gas contains a low volume of organic
compounds and is less soluble in the polymer matrix
compared to the organic compounds, and therefore,
15 the inorganic gas remains essentially in the voids
of the solid particles for an expansion of the
particles.

For the process of the invention, the expandable
polymer particles may be conventional expandable
20 polymer, e.g. expandable polystyrene (EPS) particles,
expandable polypropylene (EPP) particles, expandable
polyethylene (EPP) particles, containing an
inorganic or an organic blowing agent, as discussed
above. The expandable polymer particles may be pre-
25 pre-nucleated particles prepared in accordance with
the teachings of U.S. Patent No. 6,538,042 (WO
00/15703) and U.S. Patent No. 6,455,599 B1 (WO
00/15704), or the particles may be those prepared in
accordance with the teachings of U.S. Patent No.
30 6,573,306 B1 (WO 00/15702), the disclosures of which
are all incorporated herein in their entirety by
reference.

The blowing agent in the particles of the
aforesaid patents, and therefore, the invention may
35 also be carbon dioxide.

5 The expandable polymer particles may contain water that is blended with the aliphatic hydrocarbons blowing agents or water can be used as the sole blowing agent as taught in U.S. Patent Nos. 6,127,439; 6,160,027; and 6,242,540 assigned to NOVA
10 Chemicals (International) S.A. In these patents, water-retaining agents are used. The weight percentage of water for use as the blowing agent can range from 1 to 20%. The disclosures of U.S. Patent Nos. 6,127,439, 6,160,027 and 6,242,540 are
15 incorporated in their entirety herein by reference.

 The expandable polymer particles may be produced via an extruder that has an under water cutter for forming small spherical pellets. In the extruder, a chemical blowing agent that releases
20 carbon dioxide gas may be used as the blowing agent where the blowing agent is mixed into the polymer to "pre-nucleate", i.e. form cells in the polymer, as it exits the extruder die. Additional blowing agents such as gaseous carbon dioxide, pentane,
25 HCFC'S, and CFC'S can also be added directly to the extruder. Also, expandable particles may be produced in an extruder with a blowing agent, e.g. pentane and without foaming at the die, for example when making non-nucleated particles.

30 The expandable polymer particles may be foamed cellular polymer particles as taught in Arch et al. U.S. Patent Application Serial No. 10/021,716 assigned to NOVA Chemicals Inc. The foamed cellular particles are preferably polystyrene that are pre-
35 expanded to a bulk density ranging between 600 kg/m³ to about 200 kg/m³, and contain an organic blowing

5 agent level less than 6.0 weight percent, preferably
ranging between 2.0 wt % to 5.0 wt %, and more
preferably ranging between 2.5 wt % to 3.5 wt %
based on the weight of the polymer. The disclosure
of U.S. Serial No. 10/021,716 is incorporated in its
10 entirety herein by reference.

If the expandable polymer particles are foamed
cellular polymer particles as discussed in the
preceding paragraph or if the expandable polymer
particles are conventional EPS particles, then there
15 may be a sufficient amount of blowing agent in the
particles that the pressurization step may not be
necessary, for example, if the pentane level in the
particles is at least 2% by weight. The
pressurization step of the invention assures that
20 there is adequate pressure in the particles,
regardless of the type and amount of blowing agent
in the particles so that the particles can be
adequately fused together in the molding step.

In broadest terms, the invention relates to a
25 process for processing expandable polymer particles
that comprises a pressurization step, a pre-
expansion step that includes a drying step, and a
molding step. The particles may contain voids,
cells, or cell-nucleating sites depending on the
30 process the raw beads had been subjected to prior to
being subjected to the process of the invention.
For example, if the raw beads are pre-nucleated in
accordance with the teachings of U.S. Patent No.
6,538,042 (WO 00/15703) and/or U.S. Patent No.
35 6,455,599 B1 (WO 00/15704), the beads used in the
process of the invention will generally contain

5 cells. If the raw beads are "non-nucleated", i.e. first processed according to the teachings of U.S. Patent No. 6,573,306 B1 (WO 00/15702), the beads used in the process of the invention will generally contain cell-nucleating sites.

10 In the pressurization step, the expandable polymer particles may have a bulk density ranging from about 600 kg/m³ and in some instances, as low as about 16 kg/m³. Preferably, the expandable polymer particles will have a bulk density ranging between
15 about 200 kg/m³ to about 600 kg/m³, and in some instances, ranging between about 250 kg/m³ and 500 kg/m³. In the pressurization step, the particles are subjected to a compressed gas at a pressure ranging between about 500kPa to about 8000kPa and at
20 a temperature ranging between -20°C to 130°C for a period of 15 minutes to about 7200 minutes (5 days), preferably less than 1440 minutes (24 hours) until the gas pressure in the particles, i.e. voids, cell-nucleating sites, or cells is sufficient for the
25 required density reduction. If the pressure of the gas being applied to the particles is 2500kPa, then the particles may be subjected to this gas at this pressure until a pressure of 2500kPa is attained in the particles.

30 As stated in the preceding paragraph, the temperature of the gas in the pressurization unit preferably will range between -20°C to 130°C. However, it has been found by the inventors that for expandable polystyrene particles temperatures higher
35 than 90°C tend to soften the polystyrene, and therefore, the temperature for expandable

5 polystyrene needs to be about 90°C or less. Also,
it has been found that for expandable polystyrene
particles in the pressurization unit, a period of
one hour to about eight hours will be sufficient to
achieve the desired pressure in the particles in
10 preparation for the pre-expansion unit.

It will be appreciated that a lower density
particle would require a lower pressure for the gas
being supplied to the pressurization unit. That is,
if the particles entering the pressurization unit
15 have a density of about 16 kg/m³, then the pressure
in the pressurization unit may be below 500kPa (5
bars), i.e. about 50kPa (0.5 bar) to about 100kPa
(1.0 bar) since a high pressure of 8000kPa (80bar)
will tend to crush the foam and to break the cells
20 in the particles, etc., especially if the pressure
is raised too quickly in the pressurization unit.

In order to assist in maintaining a desired
and/or required pressure in the expandable particles
obtained in the pressurization step, the particles
25 can be conveyed through suitable means at a
pressure, for example, of about 50kPa to about
200kPa, from the pressurization unit to the pre-
expansion unit.

For the pre-expansion step, a pressure vessel is
30 generally used. The pressure vessel may be an
automatic batch device and the pre-expansion step
may involve a continuous process. For example, the
particles may flow into the pressure vessel on its
one side, be pre-expanded and dried, and exit from
35 the pressure vessel to the mold on its other side.

5 Expansion of the particles occurs in the pre-expansion step via a heating medium, which may have a temperature ranging between 100 to 120°C (212°F to 248°F) and a pressure ranging between 50 to 200kPa. The heating medium is applied to the particles for
10 about 5 to 120 seconds to pre-expand the particles to a density ranging between about 193 kg/m³ to about 8 kg/m³ (i.e. about 12 pounds/cubic foot to about 0.5 pounds/cubic foot). For example, if according to conventional practice the density of the particles
15 in the pressurizing step is about 600kg/m³ than according to conventional practice, the density of the particles as a result of the pre-expanding step will be about 8 kg/m³. The heating medium may be any conventional heating medium, e.g. steam, hot air,
20 hot water, radiant heat, convection heat, micro-wave heat, high frequency radiation, or electromagnetic.

 Because there is a pressure differential between the pressure in the particles and the pressure in the pre-expansion unit, the particles will expand.
25 The pressure remaining in the particles allows the particles to be molded.

 One generally accepted method for pre-expansion of impregnated thermoplastic particles is taught in U.S. Patent No. 3,023,175 to Rodman that uses steam
30 for pre-expanding the particles. In the invention, the particles may be pre-expanded in a similar manner. However, as stated herein above, a certain pressure will remain in the particles while steam is applied for the expansion of the particles. The
35 pressure in the pre-expansion unit may be maintained in the pre-expansion unit for the drying step.

5 The particles may be dried by injecting a flow
or stream of hot dry air through the pre-expansion
unit and onto the particles. During the drying
step, the particles are consistently kept under a
higher pressure so as to maintain an overpressure in
10 the particles. This drying step may continue until
the water vapor from the steam evaporates from
inside the particles.

 If the pressure in the pre-expansion unit is
between 50kPa to 200kPa, then the pressure in the
15 particles may range generally between 50kPa and
200kPa. If the pressure in the pre-expander is
brought down to about 30kPa, then the particles may
remain in the pre-expander until the pressure in the
particles is about equal to that in the pre-
20 expander.

 As mentioned herein above, according to
conventional practice, after the particles are pre-
expanded, the pressure in the pre-expander is
gradually brought down to zero and air is injected
25 through the pre-expander and vented there from.
However, in the invention the pressure in the pre-
expansion unit is maintained, and for the drying
process of the particles, preferably hot dry air is
injected into the pre-expander and is retained
30 instead of being completely vented into the external
environment. This hot dry air may have a
temperature ranging from about 20° to about 90°C and
a pressure ranging from about 1kPa to about 10kPa.
The hot dry air may be directed to flow over the
35 particles for about 1 to about 900 seconds without
venting all the pressure from the particles and

5 without venting all the air into the environment,
the result being that very little or no residual
hydrocarbons, e.g. pentane, generally used as a
blowing agent in EPS particles, are emitted into the
atmosphere.

10 The pre-expanded, dried particles can be
immediately transferred to a conventional molding
machine. Foam articles are molded under pressure in
the presence of steam using any of a number of
methods and apparatus that are well known to those
15 skilled in the art.

When the particles exit the pre-expansion unit,
the particles will be over-pressurized, e.g. having
a pressure ranging from about 30kPa to about 200kPa.
When the beads enter the molding machine, the
20 partial gas pressure inside the particles is greater
than the air pressure inside the molding machine,
which allows the particles to further expand and
fuse together upon further heating.

For the molding step, the process of the
25 invention uses the residual gas pressure, and in
some instances, the residual blowing agent in the
particles to adequately fuse the particles together.
If there is very little or no residual blowing agent
in the particles for the molding step, then the
30 residual gas pressure in the particles will be
sufficient to adequately fuse the particles
together.

As discussed herein above, the production rate
of the molding machine may be such that the
35 particles cannot be immediately transferred to the
molding machine after the pre-expanding/drying

5 steps. In this instance, the particles can be
conveyed to a pressure silo, which may be connected
to the molding machine. The pressure silo is
constructed such that pressure will be held and
maintained in the particles. This pressure in the
10 particles may range from about 30kPa to about
200kPa.

In the invention, a relatively high pressure is
first created in the particles and then an adequate
pressure is maintained in the particles throughout
15 the pre-expanding and drying steps so that an
adequate pressure exists in the particles for the
molding step.

From the above, it can be appreciated that the
process of the invention provides for a sufficient
20 pressure existing in the particles for the pre-
expanding/drying steps and for the molding step
regardless of the amount and/or type of blowing
agent initially incorporated in the particles or
remaining in the particles in the pre-expanding and
25 molding steps. In the pre-expanding, drying, and
molding steps, the particles are expanded by using
the residual gas pressure, and in some instances,
the residual blowing agent in the particles.

Suitable gases for the pressurization unit are
30 air, carbon dioxide, nitrogen, and mixtures thereof.
The preferred gas is selected from the group
consisting of air, carbon dioxide, and mixtures
thereof.

The process of the invention may find
35 particular application with water blown expandable
polymer particles, preferably water blown expandable

5 polystyrene particles (WEPS), which uses water as
the blowing agent, as those particles disclosed in
the aforesaid U.S. Patent Nos. 6,127,439; 6,160,027;
and 6,242,540. In order to achieve densities of 20
kg/m³ or less, it has been found that the injection
10 of high pressurized gas, i.e. ranging between 500 to
2500 bars for about 15 minutes to about 7200 hours
at temperatures ranging between 20 to 90°C according
to the teachings of the invention creates an
equivalent pressure in the "cell nuclei". This
15 pressure existing in the cells of the particles can
then be used to expand the polymer of the particles
where the high pressure inside the particles causes
the expansion of the cells resulting in the desired
lower densities of 20 kg/m³ or less.

20 As discussed herein above, for the
pressurization step, the particles are subjected to
a highly pressurized gas. This highly pressurized
gas, in effect, may be used as the blowing agent.
The applying of this highly pressurized gas to the
25 particles can occur at the molder's location prior
to the particles being pre-expanded and molded.
The applying of this high-pressured gas to the
particles at the molder's facility may eliminate the
shelf-life problem generally associated with
30 conventional EPS in which all the blowing agent,
e.g. pentane is added at the resin supplier's
facility.

In the pressurization step, the pressurized gas
may be air. It has been found that the use of
35 pressurized air may eliminate some of the
disadvantages associated with the use of water as

5 the blowing agent. The diffusion rate of air
through polystyrene is less efficient and therefore
less rapid than water vapor, and therefore, air
generally will remain in the particles for a longer
period of time than water. Air can be heated to any
10 temperature and still be effective in pressurizing
the particles, whereas water and pentane, the most
common blowing agents, need to be heated above their
boiling point in order to soften and expand the
polymer. Another advantage of using pressurized air
15 in the particles is that air does not condense in
the cells after expansion, thereby contributing to
the elimination of the maturing step between the
pre-expansion and molding steps.

 Alternatively, for the pressurization step, the
20 pressurized gas may be carbon dioxide. There is an
advantage in using carbon dioxide as the pressurized
gas in the pressurization step and as a blowing
agent in the particles, especially those that are
pre-nucleated or non-nucleated particles prepared
25 according to the aforesaid U.S. Patent Nos.
6,455,599, 6,538,042, and 6,573,306, or are solid
polystyrene particles that are impregnated with
carbon dioxide gas and then pre-nucleated according
to U.S. Patent No. 6,573,306 in that the efficiency
30 of the process of the invention generally may be
increased. Carbon dioxide is better soluble in the
polymer matrix, and a higher load of pressurizing
gas may therefore be obtained for carbon dioxide
compared to air or nitrogen. Also, the kinetics of
35 carbon dioxide absorption is better. Finally, a
carbon dioxide based process may allow the recycling

5 of industrial CO₂, thereby making better use of this greenhouse gas.

The process of the invention essentially involves pressurizing expandable polymer particles, pre-expanding and drying the pressurized particles, and directly placing the pre-expanded particles into the molding machine. It is apparent that both the aging bag, which is used conventionally for the processing of EPS particles, and a second pressure vessel, which is used conventionally for processing EPP and EPE particles, may be eliminated.

As stated herein above, the particles may be expandable polyethylene (EPE) or expandable polypropylene (EPP). For these particles, the common blowing agents such as pentane, carbon dioxide, or CFC'S diffuse out of the particles very quickly so that the unexpanded beads impregnated with the blowing agent cannot be easily shipped to the molder's location for expansion.

Instead, a typical process for EPE and EPP particles is to first produce extruded mini-pellets with suitable additives. These mini-pellets are then suspended in water with suspending agents in a manner known to those skilled in the art. The blowing agents are added at high temperatures and pressures in relatively small pressure vessels. While the pellets are still at a high temperature and pressure, the vessel contents are quickly discharged to atmospheric pressure where the particles expand to final bulk densities ranging from about 16kg/m³ to about 80kg/m³ (1 to about 5 lbs/ft³). The fully expanded particles are aged and

5 dried prior to conveying, packaging, and shipping to
the molder's location. This generally involves the
associated costs of shipping "air", i.e. very light
weight particles long distances.

10 Once at the molder's location, the particles
usually need to be re-inflated with a gas, typically
air, prior to molding. This requires large pressure
vessels since the bulk density of the particles is
extremely low. The air pressure must be gradually
increased over a 4 to 24 hour period in order to
15 avoid the particles from collapsing which generally
happens if the pressure is excessive and applied
rapidly. Once the particles are inflated, they must
be held under pressure and/or molded quickly before
the air within the cell structure dissipates.

20 The process of the invention may be
particularly applicable in processing EPP and EPE
particles. The pressurization unit can be located
at the molder's location and used prior to pre-
expanding and molding.

25 The invention is further illustrated, but is
not limited by, the following examples, which
pertain to expandable polystyrene particles.

Examples

Example 1

30 This example pertains to pre-nucleated
polystyrene beads containing water as a blowing
agent. These beads were produced in accordance
with the teachings of the aforesaid U.S. Patent No.
6,127,439 which discloses the use of polar water
35 absorbing polymers as water retaining agents, and
in accordance with the teachings of the aforesaid

5 U.S. U.S. Patent No. 6,538,042 (WO 00/15703) and
U.S. Patent No. 6,455,599 B1 (WO 00/15704), which
respectively disclose pre-nucleated beads and a
process to obtain these beads.

10 This example shows that the pre-nucleated beads
can be expanded and molded by first pressurizing
the beads, and then pre-expanding and molding the
beads without maturing the beads between the pre-
expansion and molding steps.

15 In order to obtain pre-nucleated beads, about
4-liters of beads (screened size fraction 0.900-
1.250 mm) were partially expanded with steam in an
Erlenbach PVD-80 batch pre-expander (previously
Polytech PVD-80). The initial density of the beads
prior to pre-nucleation was about 600 kg/m³, and
20 the density of the slightly expanded pre-nucleated
beads was about 419 kg/m³.

These four liters of pre-nucleated beads were
then pressurized in a batch vessel (having a 4
liter volume) with compressed air at 2250kPa for 16
25 hours at room temperature and then were transferred
under 200kPa pressure to an agitated 100-liter
expansion vessel. This expansion vessel had an air
pressure of 5kPa. The beads were treated with
steam at a supply pressure of 70kPa for 20 seconds
30 to expand them to a final density of 34 kg/m³. The
resulting wet foamed beads (referred to as "pre-
puff" or "pre-foam") were then dried by blowing air
at room temperature for 180 seconds through the
pre-expansion vessel while a positive pressure of
35 30kPa was retained in the vessel. From the
expansion vessel, the beads were transported to a

5 conventional molding machine (Kurtz K45 with a
molding cavity measuring 300mm by 300mm by 50mm).
The residual air pressure inside the beads acted as
a blowing agent during the subsequent molding step.
In the molding machine, the pressure was released
10 and the machine was operated at a conventional
molding cycle, i.e. set pressure of 100kPa; steam
time of 8 seconds; and foam pressure demolding of
15kPa.

The resultant foam molding had a density of 37
15 kg/m³. From visual inspection, the beads were well
fused and virtually no shrinkage of the foam
occurred. The cross-breaking strength of the
resultant foam was measured according to CEN 12089
with a value of 204 N at this foam density.

20 Example 2

This example involves pre-nucleated polystyrene
beads that contain a small amount of pentane as a
blowing agent. These pre-nucleated beads were
produced in accordance with the teachings of the
25 aforesaid U.S. U.S. Patent No. 6,538,042 (WO
00/15703) and U.S. Patent No. 6,455,599 B1 (WO
00/15704). The process and equipment for Example 2
were similar to that used in Example 1.

This example shows that pre-nucleated beads can
30 be expanded and molded by first pressurizing the
beads, and then pre-expanding and molding the beads
without maturing the beads between the pre-expanding
and molding steps.

In order to form the pre-nucleated beads, about
35 4.0 liter of beads having an initial density of
about 600 kg/m³ and containing about 1.9% by weight

5 pentane as the blowing agent were partially expanded with hot air to a lower density of 400 kg/m³. The amount of blowing agent that remained in the beads after this partial expansion was 1.2% by weight based on the weight of the beads.

10 These four liters of pre-nucleated beads were then pressurized in a batch vessel of Example 1 with compressed air at 2250kPa for 16 hours at room temperature and then transferred under 200kPa pressure to the agitated expansion vessel of Example 15 1. The expansion vessel had an air pressure of 5kPa. The beads were then treated with steam at a supply pressure of 70kPa for 20 seconds to expand them to a final density of 19 kg/m³. The resulting wet foamed beads were then dried by blowing air at 20 room temperature for 180 seconds through the pre-expansion vessel while a positive pressure of 30kPa was retained in the vessel. From the expansion vessel, the beads were transported to a conventional molding machine of Example 1. In the molding 25 machine the pressure was released and the machine was operated at a conventional molding cycle with the same settings as that of Example 1.

 The resultant foam had a density of 19.5 kg/m³. From visual inspection, the beads were well fused and virtually no shrinkage of the foam occurred. 30 The cross-breaking strength of the resultant foam was measured according to CEN 12089 with a value of 176 N at this foam density. This value is comparable to that obtained with conventional EPS 35 beads.

Example 3

5 Raw beads similar to that used in Example 2
were pre-nucleated to a density of about 380kg/m³,
and were processed similar to that of Example 2.
The pressure in the pre-expander was held at 30kPa.
These particles before molding had a density of
10 17kg/m³. The particles were transferred to a
pressure silo where a pressure of 30kPa was applied
to the particles. The particles were then molded
for 23 seconds at a steam pressure of 90kPa. The
foam produced had a density of 20kg/m³. The cross
15 breaking strength was measured according to CEN
12089 with a value at this density of 221 N.

Several additional runs were performed with the
raw beads where the pressure in the pre-expander was
decreased until 15kPa for the first run, 10kPa for
20 the second run, and 8kPa for the third run. The
respective densities of the beads before molding
were 15kg/m³, 16kg/m³, and 16kg/m³. The beads were
molded for 17 to 19 seconds at a steam pressure of
90kPa. The foam produced had a density of 18kg/m³,
25 19kg/m³, and 18kg/m³, respectively with respective
cross breaking strengths of 183N, 172N, and 163N.

This example illustrates that the lower the air
pressure of the pre-expander, the lower the value of
the cross breaking strength. Thus, it may be more
30 desirable in most instances to maintain a pressure
of 30kPa or greater in the pre-expander for better
strength foam products.

Example 4

This example pertains to solid polystyrene
35 beads that are impregnated with carbon dioxide and
then pre-nucleated, i.e. slightly expanded to 400

5 kg/m³, similar to the teachings of the aforesaid U.S. Patent No. 6,573,306. This example also uses air as the pressurized gas in the pressurization unit.

This example shows that beads impregnated with carbon dioxide and then pre-nucleated can be over-
10 pressurized with air, pre-expanded, and molded without maturing the beads between the pre-expansion and molding steps.

To produce the beads initially used in this example, about 20 liters of solid polystyrene beads
15 with a density of 630 kg/m³ were pressurized in a pressure vessel with carbon dioxide for 3 hours at a pressure of 500 kPa at room temperature so as to impregnate the beads with carbon dioxide. This impregnation step was followed by a pre-nucleation
20 step with a batch steam expander (Erlenbach PVD-80). The pre-nucleated beads were then processed with equipment and conditions similar to that of Example 1. That is, the pre-nucleated beads were then pressurized in a batch vessel (having a 4 liter
25 volume) with compressed air at 2250kPa for 16 hours at room temperature and then were transferred under 200kPa pressure to an agitated 100-liter expansion vessel. This expansion vessel had an air pressure of 5kPa.

30 The beads were treated with steam at a supply pressure of 70kPa for 20 seconds to expand them to a final density of 20 kg/m³. The resulting pre-puff beads were dried by blowing air at room temperature for 180 seconds through the pre-expansion vessel
35 while a pressure of 30kPa was retained in the pre-expansion vessel.

5 From the pre-expansion vessel, the beads were transported to a conventional molding machine (Kurtz K45 used in Example 1). The residual air pressure in the beads helped to expand the beads further in the molding step. In the molding machine, the
10 pressure was released and the machine was operated at a conventional molding cycle, i.e. set pressure of 100kPa; steam at 8 seconds; and foam pressure demolding of 15kPa.

 The resultant foam molding had a density of 26
15 kg/m³. From visual inspection, the beads were well fused and virtually no shrinkage of the foam occurred. The cross-breaking strength of the resultant foam was measured according to CEN 12089 with a value of 330 N at this foam density.

20 While the present invention has been set forth in terms of specific embodiments thereof, it will be understood in view of the instant disclosure that numerous variations upon the invention are now enabled yet reside within the scope of the
25 invention. For example, it is to be appreciated that both the pre-expansion and the molding units may be equipped with a separate pressure supply source. Accordingly, the invention is to be broadly construed and limited only by the scope and
30 spirit of the claims now appended hereto.

5 WHAT IS CLAIMED IS:

1. A process for processing expandable polymer particles, comprising:

10 a) pressurizing said expandable polymer particles with a high pressurized gas to create a high gas pressure inside said particles;

b) pre-expanding said particles with a heating medium at a pressure ranging above atmospheric pressure and below the gas pressure in said particles as a result of step a) and drying the pre-

15 expanded particles; and

c) immediately molding said particles into a foam article using at least the residual gas pressure in said particles.

2. A process of claim 1, wherein said drying of said pre-expanded particles in step b) occurs while said particles are kept under a pressure ranging above atmospheric pressure and below the gas pressure of step a).

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3. A process of claim 1, wherein said gas in the pressurizing of said particles of step a) has a temperature ranging from about -20° to about 130°C and a pressure ranging from about 500kPa to about 8000kPa and said pressurizing occurs for about 15 to about 7200 minutes.

25

4. A process of claim 3, wherein said polymer is polystyrene and said gas has a temperature of about 90°C or less.

30

5. A process of claim 4 wherein said heating medium for said pre-expanding of said particles of step b) has a temperature ranging from about 100°C to about 120°C and a pressure ranging from about 50

35

5 kPa to about 200 kPa and is applied to said particles for a time ranging from about 5 to about 120 seconds.

6. A process of claim 2 wherein said drying of said expanded particles in step b) consists of an
10 air flow having a temperature ranging from about 20° to about 90°C and a pressure ranging from about 1 kPa to about 10 kPa and is applied to said particles for a time ranging from about 1 to about 900 seconds.

15 7. A process of claim 1 wherein said process further comprising:

 after pre-expanding of said particles of step b) and prior to said molding of said particles of step c), transferring said particles to a pressure
20 silo to maintain the pressure in said particles.

8. A process of claim 1 wherein in steps b) and c), the pressure in said particles is maintained at least at a pressure ranging from about 50kPa to about 200kPa.

25 9. A process of claim 1 wherein said pressurized gas in step a) is selected from the group consisting of air, nitrogen, carbon dioxide, and mixtures thereof.

10. A process of claim 1 wherein said pressurized
30 gas in step a) is selected from the group consisting of air, carbon dioxide, and mixtures thereof.

11. A process of claim 1 wherein said heating medium in said step b) is selected from the group consisting of steam, hot air, hot water, radiant
35 heat, micro-waves, high frequency radiation, and electromagnetic waves.

5 12. A process of claim 1 wherein said polymer is selected from the group consisting of polystyrene polyethylene, polypropylene, and an interpenetrating network of polyethylene and polymerized vinyl aromatic resins.

10 13. A process of claim 12 wherein said polymer is polystyrene.

14. A process of claim 1 wherein said expandable polymer particles contain a blowing agent selected from the group consisting of an inorganic blowing agent, an organic blowing agent, and mixtures thereof.

15 15. A process of claim 1 wherein said expandable polymer particles are polystyrene, are pre-nucleated, and contain an organic blowing agent in an amount less than 3 percent by weight based on the weight of the particles.

20 16. A process of claim 1 wherein said expandable polymer particles are pre-nucleated and contain an inorganic blowing agent selected from the group consisting of carbon dioxide, nitrogen, air, water, and mixtures thereof, and wherein said pressurized gas in step a) is selected from the group consisting of air, nitrogen, carbon dioxide, and mixtures thereof.

25 17. A process of claim 1 wherein said expandable particles are pre-nucleated and contain carbon dioxide as the blowing agent, and wherein the gas in step a) is selected from air and carbon dioxide.

30 18. A process of claim 1 wherein said expandable particles are comprised of solid polystyrene particles that are impregnated with carbon dioxide

5 and then pre-nucleated, and wherein the pressurized gas in step a) is selected from air and carbon dioxide.

19. A foam article formed from the polymer particles processed according to the process of claim 1.

10 20. Particles processed according to steps a) and b) of the process of claim 1.

21. An apparatus for processing expandable polymer particles, comprising:

15 a pressurization unit for pressurizing said particles with a pressurized gas to create a gas pressure in said particles that is greater than the pressure outside said particles;

20 a pre-expander unit for applying a heating medium at a temperature ranging between about 100°C and 120°C and a pressure ranging above atmospheric pressure and below the gas pressure in the particles so that the residual gas pressure in the particles is used as the blowing agent and said pre-expander unit including drying means for drying said

25 particles in said pressure ranging above atmospheric pressure and below the gas pressure in said particles until the particles are dry, and

 a molding unit for forming a foam article.

30 22. An apparatus of claim 21 wherein said pressurized gas in said pressurization unit is selected from the group consisting of air, nitrogen, carbon dioxide and mixtures thereof.

35 23. An apparatus of claim 21 wherein said pressurized gas in said pressurization unit is selected from the group consisting of air, carbon dioxide, and mixtures thereof.

5 24. An apparatus of claim 21 wherein said heating
medium in said pre-expander unit is selected from
the group consisting of steam, hot air, hot water,
radiation, microwave, high frequency radiation, and
electromagnetic radiation.

10