

July 6, 1965

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3,192,560

APPARATUS FOR HEAT TREATING POROUS SHEET MATERIAL

Filed Nov. 8, 1963

4 Sheets-Sheet 1

FIG. 1

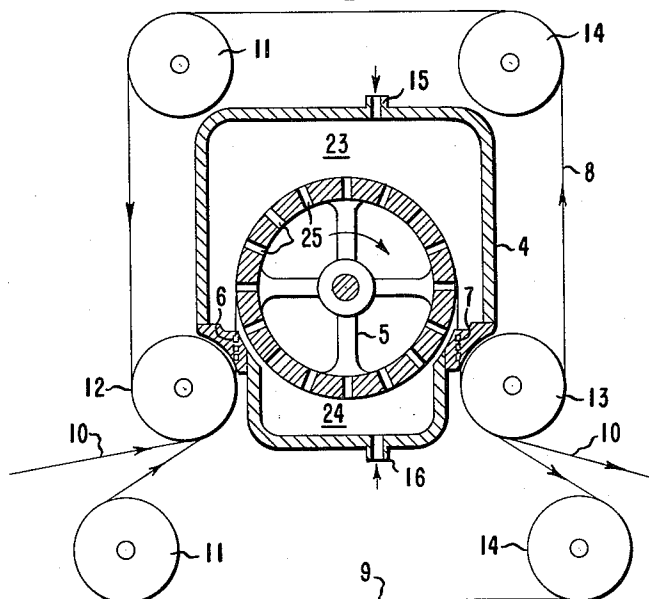
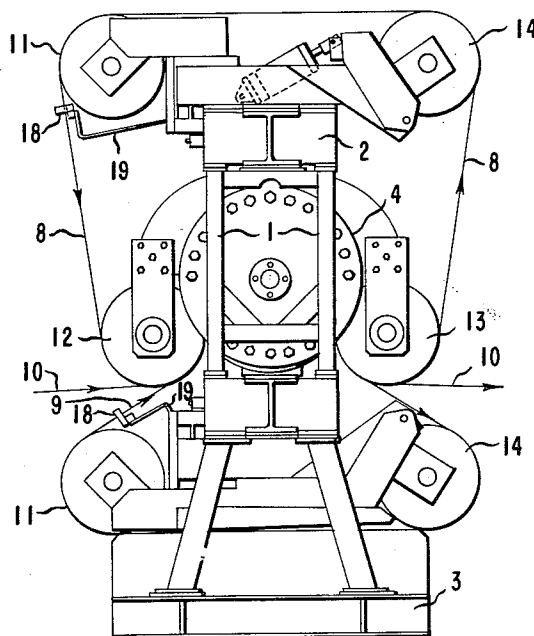


FIG. 2



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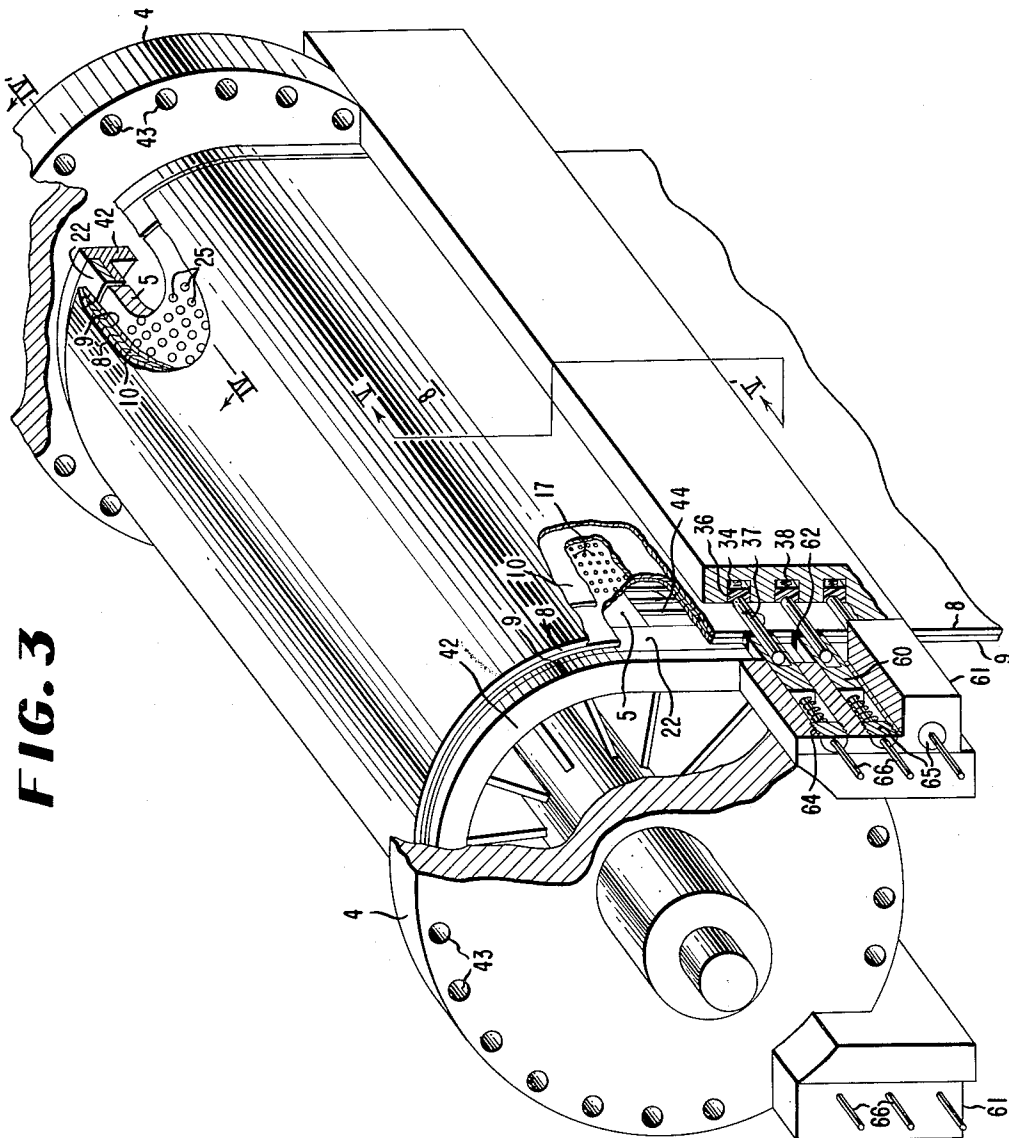
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APPARATUS FOR HEAT TREATING POROUS SHEET MATERIAL

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4 Sheets-Sheet 2



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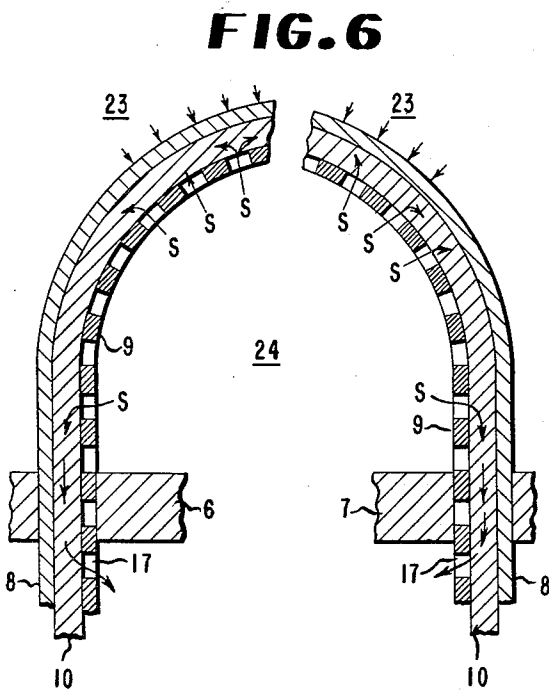
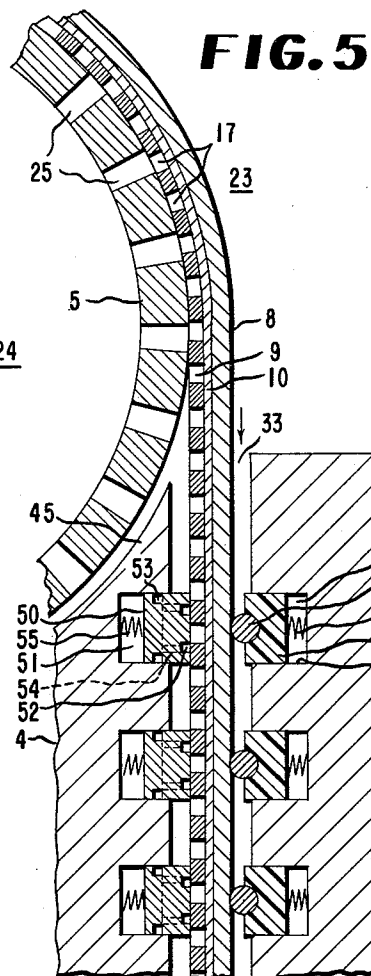
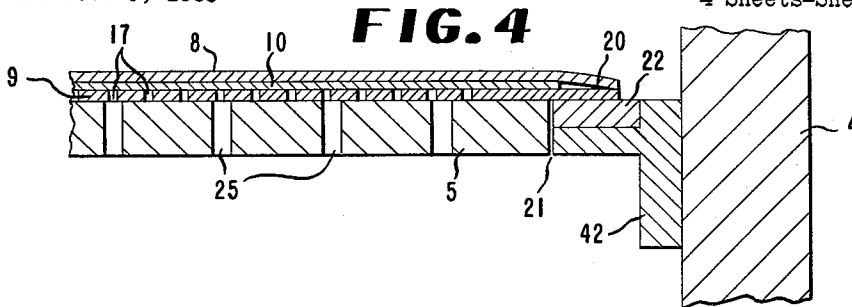
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4 Sheets-Sheet 3



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APPARATUS FOR HEAT TREATING POROUS SHEET MATERIAL

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11 Claims. (Cl. 18—1)

This invention relates to an apparatus for uniform heat-treatment of porous sheet materials, in particular to an apparatus for effecting such heat treatment while maintaining a restraint on the surface of the sheet to prevent or minimize any change in area dimensions.

The heat treatment of porous sheet materials, for example nonwoven fabric webs or paper-like sheet structures, is often required in order to activate a binder material therein, to modify the surface for decorative or smoothing effects, to cause spontaneous elongation of the constituent fibers thereby developing fiber crimp, or for other known purposes. In many instances the heat treatment requires the use of a closely controlled temperature and rapid attainment of that temperature in order to prevent adverse effects upon the resulting sheet material.

While nonwoven fabrics can be bonded by any of the well-known solvent, adhesive or heat bonding techniques, the latter in which the fibers are self-bonded at a multiplicity of fiber intersection points possesses distinct advantages in terms of cost and the avoidance of the extra steps which are otherwise needed to apply a binder material and remove a volatile carrier should one be used. Moreover, special effects can be often achieved by self-bonding techniques which are not readily attainable by other methods. A notable disadvantage of the self-bonding techniques as heretofore practiced, however, has been the lack of equipment which, when employed in a continuous operation on a commercial scale, will provide the high degree of precision required with respect to temperature control. Thus if the temperature is not consistently maintained at a sufficiently high level, areas of the fabric may possess an inadequate number of satisfactorily strong bonds. Excessively high temperatures, on the other hand, give rise to over-bonding even to the point where the fiber structure collapses. In the case of oriented fibers such as crystalline oriented polypropylene, these being of particular value in nonwoven fabrics, the use of temperatures near the incipient melt point or stick temperature tends to deorient the fibers to such an extent that much of their inherent high strength is destroyed. Even apart from the temperature control problem which previously has been associated with self-bonding equipment, problems have also been experienced in preventing excessive fiber shrinkage during bonding. This problem has proven to be particularly acute with crystalline polypropylene fibers since it has been observed that they tend to undergo excessive shrinkage even when bonded under carefully controlled conditions. Particular care must therefore be exercised to ensure that such fibers are properly restrained during the heating operation.

In processing a loose bulky web of nonwoven fibers, it is desirable to expose all the fibers to a similar heat treatment so that the resultant product has a uniform distribution of equal bond points throughout its dimensions. In practice, subjecting a web of this kind to such critical heat treatment by conventional means, gives rise to some exceedingly difficult and sophisticated heat transfer problems. This is largely due to the high amount of dead air space contained in the web. The air is not only a relatively poor heat transfer medium but, during actual treatment, appears to absorb a large portion of thermal energy so that great quantities of the heating medium must be

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supplied at a relatively high temperature. Although high heat transfer rates may be established by introduction of the heating medium at a considerably higher temperature than the melt point of the fibers, in doing so, the fibers located near the surface of the web become overheated and frequently destroyed before the inner ones barely attain bonding conditions. Conversely, introduction of the heating medium at or near the melt point results in a correspondingly lower heat transfer rate requiring longer exposure of the web at the elevated temperature; from the standpoint of economics, the additional time to achieve the proper degree of bonding is prohibitively long.

Moreover, in processing nonwoven webs of polypropylene or other fibers some means must be employed to restrain shrinkage in that portion of the web undergoing treatment. The character of the restraint must not only be sufficiently low in magnitude so as not to crush the fibrous structure but it must be applied very uniformly in a bi-directional manner across the web, otherwise non-uniform shrinkage of the fibers will occur resulting in an inferior and unattractive product. The problem becomes increasingly troublesome as larger width webs are processed on a continuous basis; in which case, the ability to place a uniform restraint on the web determines to a large extent whether the product is commercially saleable.

It is accordingly an object of the invention to provide an apparatus for uniform heat treatment of wide sheet materials under closely controlled temperature conditions.

Another object of the invention is to provide an apparatus for heat treating a continuous web of material which is capable of supplying large quantities of heat at a high rate within a narrow, precisely controlled temperature range near the lower end of the melting point range of the material.

A further object of the invention is to provide an apparatus for heat treating a continuous web of material of very wide dimensions, under uniformly distributed restraining forces during the heat treatment.

A still further object of the invention is to provide an apparatus for heat treating a continuous web of material by uniformly heating the web and rapidly cooling it after treatment.

The apparatus of the invention comprises a pressure vessel having entrance and exit openings and containing first and second restraining means each providing an endless conveying surface. The endless conveying surfaces are positioned adjacent opposite major surfaces of the sheet material so that the sheet material is caused to pass, in sandwich fashion, into the entrance opening through the vessel and out the exit opening. The first restraining means comprises a substantially imperforate flexible band, such as a metal belt, which divides the vessel into two generally fluid tight chambers during its travel therethrough. On one side of the imperforate belt is a first chamber through which the sheet material passes; on the other side is a second fluid tight chamber. Each chamber is provided with a means for establishing a fluid under pressure therein, i.e., so that the chambers are separately pressurized. The fluid in the first chamber is a heated fluid, the fluid in the second chamber may be heated or unheated. The second restraining means is perforate so that the heated fluid of the first chamber can flow therethrough and communicate with the sheet material passing through the vessel and effect the desired treatment, e.g., bonding. Additionally this second restraining means also functions as a support such that upon establishment of a higher fluid pressure in the second chamber than exists in the first chamber, the sandwich is securely held together under restraining forces.

As will be apparent from the illustrated embodiments

and the detailed discussion hereinafter, the invention is susceptible of numerous variations. In one embodiment, for example, the second restraining means which provides a support during imposition of the restraining forces can comprise a foraminous rotatable drum provided with a perforated endless band. Alternatively it can comprise a foraminous platen, either stationary or not and having either a planar or curved surface, which is also provided with a perforated endless band.

In a preferred embodiment of the invention, the apparatus utilizes the high heat capacity, excellent heat transfer and temperature uniformity of a saturated vapor atmosphere at superatmospheric pressure. While any saturated vapor atmosphere which does not solvate or otherwise adversely affect one or more of the constituents of the sheet material may be used, saturated steam is the preferred medium because of favorable performance, cost and availability factors. For convenience in the ensuing discussion, reference will be frequently made to steam as the heated fluid but it will be understood that the remarks apply equally to other suitable vapor atmospheres.

By the creation of separate pressurized chambers, as described above, with establishment of a pressure differential between the two, the sheet material passing through the vessel is firmly secured between endless surfaces moving at essentially the same speed as the sheet material. As a result, pressure is uniformly applied to the sheet across its surface dimensions and any tendency for it to undergo a change in area dimensions, e.g. shrinkage, is minimized. In terms of the uniformity with which the restraining forces are applied to the sheet, the utilization of a fluid pressure differential according to the invention is quite superior to mechanical tensioning devices which might appear to be satisfactory for accomplishing such an effect. This is particularly true in the case of wide webs, for example of 15 feet width or more. The apparatus of the invention possesses still other advantages, however. Thus it permits a high degree of precision with respect to temperature control because the heated fluid supplied to the first chamber quickly permeates the sheet so as to effect a uniform treatment, for example bonding, throughout the thickness dimension of the sheet. The apparatus is also of particular advantage when it is desired to simultaneously produce a patterned surface upon the sheet being treated.

Being uniquely adapted to readily provide a closely controlled temperature throughout the sheet being treated, the apparatus of the invention is of particular advantage for still another reason. Thus when utilized to create bonding sites between thermoplastic fibers in a nonwoven web, it permits rapid attainment of bonding temperatures while minimizing losses in the fiber identity or changes in the molecular orientation of the fibers. By avoiding excessive changes in the fibers, tensile strength, tear strength, and other properties of the resultant sheet material are kept at a high level.

Because of the above-enumerated advantages, the apparatus of the invention is particularly suitable for purposes of bonding nonwoven webs of crystalline oriented polypropylene. With such webs an operating steam pressure is normally selected in the range of about 38 to 131 p.s.i.g. corresponding to a temperature of about 140–180° C., and this can be readily maintained over continuous periods of operation. The apparatus of the invention is also well adapted to effect self-bonding of nonwoven sheets of film-fibril strand material, e.g. as described in Blades et al. U.S. Patent 3,081,519 issued March 19, 1963. Coherent, nonwoven sheets formed by the multidirectional overlapping deposition of such strand material are described in Belgian Patent 625,998. The uniform temperature and shrinkage restraining features of the apparatus of the invention make it possible to self-bond film-fibril sheets and produce a highly abrasion resistant surface on the sheet while maintaining a high level of opacity and uniformity of opacity.

The apparatus of this invention is further described by reference to the following drawings in which:

FIGURE 1 is a schematic representation of the operation of apparatus which utilizes a perforated drum.

FIGURE 2 is an elevational view of apparatus whose operation is schematically illustrated in FIGURE 1.

FIGURE 3 is a perspective view of the apparatus of FIGURE 2, the cover having been removed and parts having been broken away and shown in section to reveal details of construction.

FIGURE 4 is a fragmentary cross section of the apparatus of FIGURE 3 viewed along irregular line IV—IV'.

FIGURE 5 is a fragmentary cross section of the apparatus of FIGURE 3 viewed along irregular line V—V'.

FIGURE 6 is a schematic representation of the steam flow feature of the apparatus of FIGURE 3.

FIGURE 7 is a fragmentary, cross section, elevational view of a planar type embodiment of the machine.

FIGURE 8 is a perspective view of the planar type apparatus of FIGURE 7, parts having been broken away and shown in section to reveal details of construction.

As shown schematically in FIGURE 1 and in greater detail in FIGURE 2, the apparatus of this embodiment comprises a stationary frame having upright supports 1 which are spaced apart and braced at the top by a cross brace 2 and secured at the bottom to a base 3, a pressure vessel 4 fixedly secured between the supports 1 and equipped with inlets 15 and 16 for supplying an atmosphere of fluid, e.g. pressurized saturated steam from any convenient steam generator source, not shown, into each of the generally fluid tight chambers 23 and 24, respectively, a rotatably mounted drum 5 housed in the vessel 4, pressure seals 6 and 7 situated at entrance and exit openings, respectively, on either side of the vessel 4 for passing a web 10 of sheet material therethrough, upper and lower endless conveying bands 8 and 9 which enter and leave vessel 4 in a sandwiched manner through the respective pressure seals and which pass around the drum 5 conveying therebetween the sheet material 10 to be treated. The two bands, the sheet material, and the drum surface all travel at essentially the same speed through vessel 4. Optionally an additional pervious band, not shown, may be used to carry the sheet material from a supply source or web laydown operation.

Still referring to FIGURES 1 and 2, the upper band 8 is essentially an impervious endless belt of predetermined width. Being impervious, band 8 cooperates along its lateral edges with the walls of vessel 4 to separate that vessel into a first, in this case lower, generally fluid tight chamber 24 (which, of course, contains drum 5 and the length of sheet material 10 being treated) and into a second or upper generally fluid tight chamber 23. The endless band 8 is constructed of a flexible material so that upon creation of a higher pressure in chamber 23 than is provided in chamber 24, it is uniformly pressed against the sheet 10 which is supported by perforated band 9 and foraminous drum 5. In this way the necessary restraining forces upon the sheet are provided. Band 8 may be prepared from a thin gauge stainless steel sheet whose ends are butt welded together and ground flush. Its external surface, that is, the side which lies in adjacent contacting relationship with the web 10, may be cloth-faced or otherwise have an embossing pattern therein for imprinting a similar aesthetic pattern on the heat-treated product and for facilitating separation of the product after the treating operation. It should be noted that the surface of imperforate band 8 is not restricted to a cloth-facing but may have any variety of characteristics limited only by the desired end product. In addition, the band 8 may be fabricated of a temperature-resistant elastomeric material which is suitably reinforced by either a wire or fabric carcass. For example, a wire screen belt embedded in an ethylene/propylene elastomer has been shown to perform satisfactorily. The band 8 is suit-

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ably trained over a system of rolls comprising an adjustable guide roll 11, idler rolls 12 and 13, and a movable tension roll 14. Idler rolls 12 and 13 are rotatably journaled at their ends in conventional bearing supports which are fastened to suitable brackets on the supports 1. If desired, idler roll 13 may be cooled by means, not shown, to increase the rate of cooling of the sheet material as it leaves the pressure vessel.

A commercial type sensor 18 mounted on arm 19 extending from the frame, engages the edge of the belt 8 and monitors its position relative to the machine frame during operation. Belt guide roll 11 is provided with conventional adjusting means to shift and/or tilt the roll slightly in either direction along its rotational axis, thus forcing the belt to track laterally. Any lateral deviation of the belt 8 is detected and translated into a signal which activates the roll-adjusting means thereby causing the belt 8 to track laterally in a corrective direction. Once the belt 8 is adjusted and aligned with the entrance and exit seals 6 and 7, the sensor 18 is intended to respond rapidly to relatively minor deviations and initiate corrective action. Any gross lateral shifting could not only seriously damage the end seals and the belt, but could create an open condition in the seals and thereby cause excessive leakage of steam. The bands 8 and 9 as well as sheet material 10 are preferably of only a slightly narrower width than the vessel entrance and exit openings.

Tension roll 14 is rotatably journaled in a frame which is pivotally connected to the frame of the apparatus. Conventional means are employed to pivot the roll 14 outwardly thereby causing the band 8 to tighten.

The lower band 9 passes over a roll system which is functionally identical with the upper band 8 system, hence it is not described. The lower band 9 is, however, perforated to permit the passage of heated fluid from inlet 16, into the drum, and through the perforations 25 of the drum so that the fluid can contact the sheet material during its passage through the vessel. Band 9 may be constructed of a heat-resistant material, e.g. an elastomer which has been vulcanized to a fine wire screen. The principal purpose of perforations 17, shown in detail in FIGURES 4, 5, and 6, is to control steam distribution into the structure of the sheet material 10 during treatment in the vessel 4. These perforations 17 may be of circular, rectangular or other suitable geometric cross section and are sized and spaced to facilitate steam distribution and sealing at the vessel entrance and exit openings. In one embodiment, for example, the holes may be circular and may range up to 0.38 in. diameter without deleterious effects on the surface qualities of the sheet material 10. Perforations of 0.094 in. diameter are highly satisfactory when provided in sufficient frequency such that the belt comprises at least 5% open area.

As shown in FIGURE 1, the bands 8 and 9 pass around the drum 5. Band 8 divides the vessel 4 into an upper chamber 23 and a lower chamber 24. Steam is supplied to the upper chamber 23 through an inlet 15 at a slightly higher pressure than in the lower chamber 24. The differential pressure serves as the clamping means which exerts a uniformly distributed force over the area of the band 8 communicating with the chamber 23, thereby pinning it against the relatively inflexible surface of drum 5. The latter thus serves as a support for the bands and sheet during passage through the vessel 4. In this way the sheet material 10 sandwiched between the bands is firmly clamped across its major dimensions and thus shrinkage is effectively restrained.

In the preferred embodiment of this invention, a 2 p.s.i.g. differential between the chambers provides sufficient restraint on the sheet material 10 to avoid undue shrinkage during the heat treatment. Pressure differentials of up to 10 p.s.i.g. or more may be used if desired.

Drum 5 contains a plurality of openings 25 which connect the interior of the drum with the surface. These

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openings serve as passageways for the steam to enter the interior of the drum from the lower portion of chamber 24 and also serve as passageways by which the steam contacts the sheet material 10. It will be understood that a sufficient number of the drum perforations 25 must coincide with perforations 17 of band 9 in order to permit pass of steam into sheet material 10.

In the preferred embodiment, as shown in FIGURES 3 and 4, the curved surface of drum 5 is wholly contained within chamber 24. As can be seen from these figures, the width of sheet 10 is slightly less than that of bands 8 and 9. The bands are also wider than drum 5. Because of the flexibility of band 8 and owing to the greater pressure established in chamber 23, the two bands directly contact one another at the edges of the sandwich, indicated generally as area 20, in fluid tight engagement. The abutting bands in area 20 overlap projection 42 of the side walls of vessel 4. Projection 42 is a U-shaped stationary member that curves around about 180° of the drum surface. A small clearance 21 is provided between the leading edge of projection 42 and the rim of drum 5. As the drum 5 rotates with the sandwiched sheet being supported thereon, band 9 slides along the upper surface of projection 42 to form a fluid tight pressure seal. The provision of a hardened metal surface portion 22 affixed onto projection 42 assists in prolonging the life of the apparatus.

In alternative embodiment, not shown, the width of bands 8 and 9 can be less than that of the surface of drum 5. An adequate seal is obtained by causing the smoothly machined rim of drum 5 to ride in rubbing contact with the leading edge of projection 42, i.e. clearance 21 is virtually eliminated. If desired for this purpose, portion 22 may be spring loaded so as to be securely urged into contact with the rim of drum 5 to thereby accommodate any end-play and reduce wear.

With reference to FIGURES 1, 2 and 3 a pulley, not shown, is attached to one end of the shaft on which the drum 5 rotates. This is coupled to an adjustable-speed electric motor or other power source to rotate the drum at the desired rate. The drum 5, in turn, serves as the driving means for recirculating the belts 8 and 9. Auxiliary motors or controlled torque devices, not shown, synchronized with the drum-driving motor may be used to drive rolls 11, 12, 13 and 14, thereby reducing the amount of power that must be transmitted by the drum to the bands.

In the embodiment of this invention described above, the entrance and exit seals 6 and 7 are structurally and functionally identical; hence, for the sake of simplifying the discussion, only one seal arrangement will be described in detail.

In FIGURES 3 and 5, the exit seal 7 is shown in detail as comprising three stages of pressure-actuated members grouped serially along the long, relatively constricted passageway 33 formed by an extension of the vessel 4 wall. Since all three stages are structurally identical, only the innermost stage is described in detail. The effective width of the passageway 33 is slightly greater than the thickness of sheet 10 and bands. Interrupting the passageway 33, between the chamber 23 and the atmosphere, is a generally rectangular groove 34 which extends the width of the pressure vessel 4. Slidably housed in the groove 34 is a matching, generally rectangular-shaped shoe 36. The face of the shoe 36 is recessed to accommodate a cylindrical roller 37. The shoe is urged toward the bands by a plurality of spaced compression springs 38 that are housed in groove 34. The shoe fits loosely in the groove 34 so that steam from chamber 23 may readily flow along the top interface and pressurize the interior of the cavity 39. As a result there is a pressure drop from above to below roller 37. Most of the pinning force exerted by the shoe 36 is derived from the steam pressure of chamber 23; a small fraction, however, is due to springs 38 which serve to augment the pinning

effect of the steam. The magnitude of the total pinning force regulates the extent of steam seepage through the fibrous structure and determines the extent of compression of the sheet material and also the amount the sheet material is preheated and cooled. This latter effect is described later.

Shoe 36 is preferably constructed of some low-friction material, e.g. polytetrafluoroethylene, to permit the roller 37 to rotate easily in contact with impervious band 8.

While the roller-seal is preferred for use on the impervious band 8, it is not quite so suitable for use on the opposite side of the band sandwich, i.e. against the perforated band 9, because of the problem of steam leakage. Although steam leakage can be minimized by selection of a suitable design and size for the perforations in band 9 and by use of larger rollers or a greater pinning force, it is preferred to utilize a pressure-actuated shoe in direct contact with the perforated band 9. As shown in FIGURE 5, the shoe 50 can be a generally rectangular-shaped, elongated strip which is slidably housed in cavity 51 and spans the width of passageway 33. The shoe 50 is relatively loosely fitted in cavity 51 so that steam from the chamber 24 may readily flow along the top interface and pressurize the interior of cavity 51. Each shoe 50 may be modified by open grooves 52 and 53 which run parallel the length of the member and serve as steam chambers during operation. All of these grooves are connected to the interior of the cavity 51 by means of a network of passages shown generally by the numeral 54. Interposed between the backside of the shoe 50 and the bottom of the cavity 51 are a plurality of compression springs 55. These are spaced at regular intervals and serve to supplement the steam pressure by furnishing a predetermined minimum force on shoe 50, particularly during the early phases of startup operations when steam pressure is low. As shown in FIGURE 3, grooves 44 may be provided in extension 45 of the vessel wall 4 to serve as steam flow paths under band 9 adjacent to vessel openings 6 and 7.

Shoe 50 may be constructed from a suitable, non-corroding tool steel of preferably, from a low-friction material such as polytetrafluoroethylene. If desired, a pressure-activated shoe of the type shown at 50 in FIGURE 5 may also be used in direct contact with impervious band 8 in place of the roller-seal 36, 37.

The steam that leaks past the first-stage seal operates the second stage which is, therefore, at a lower pressure. Likewise, the third stage (outermost seal) operates on the steam that leaks past the second stage. In situations where the heating fluid may be other than steam and whose vapors may be a hazard to operating personnel, it is necessary to eliminate virtually all leakage to the atmosphere. This may be done by simply adding more sealing stages. For most purposes three stages provide adequate sealing since the maintenance of a set pressure condition is the prime requisite and a small loss of steam can normally be tolerated.

Means for sealing the end gap at the base of U-shaped members 42 and the ends of the pressure seals comprises a module containing three spring actuated bars which abut against the edge of the band sandwich. Referring to FIGURE 3, the end-seal member is an elongated bar 60 of rectangular cross section which is one of three that is slidably mounted in a block 61, which block in turn, is attached to the vessel 4 by conventional threaded fasteners. Bar 60 may be recessed, as shown in FIGURE 3, to receive the ends of rollers 37 which extend beyond the edge of the band sandwich. The end face 62 of bar 60, which contacts the edge of the bands, is a hardened, non-corrosive tool-steel alloy with long-wear-life properties. The other end of bar 60 abuts against a compression spring 64 that urges the bar 60 against the bands. The other end of the compression spring 64 abuts against a threaded sealing collar 65 which slidably supports a slender push rod 66. One end of the rod 66 is threadedly engaged

to the bar 60 while the other end extends externally of the vessel 4. This rod serves as a convenient means for manually retracting the bars 60 in order to open the end gap and, thereby, purge any foreign material which may have become lodged therein after prolonged operation.

In the preferred embodiment, steam in the saturated condition is used as the heating fluid to exploit the latent heat of condensation. The pressure in the chamber 24 is adjusted to maintain the steam in a saturated condition near the melt point of the fibers, thereby making it a simple matter of controlling the bonding temperature very precisely within a narrow range. For example, in effecting self-bonding of nonwoven polypropylene sheets, the steam may be maintained within $\pm 1^\circ$ C. at a pressure of about 130 p.s.i.g. Although steam is preferred, it should again be noted that other condensable fluids can be used with equal effectiveness.

Condensable fluids, as opposed to non-condensable fluids, offer a precise degree of bonding because the fluid readily permeates the fibrous structures and rapidly releases its latent heat at saturation temperature which is identical to bonding temperature. With noncondensable fluids, a suitable temperature differential would be required for rapid heat transfer. Since chambers 23 and 24 are maintained separate of one another, the same fluid need not be used in each. Thus a noncondensable heated or unheated fluid such as air could be supplied to chamber 23 while steam or other heated condensable fluid is supplied to chamber 24. As shown in FIGURE 6, chamber 24 is situated so as to promote gravity drainage of condensate within that chamber. Arrows marked "S" indicate steam entering the web 10. As best shown in FIGURE 1, any excess condensate collects at the bottom of chamber 24 below the drum 5 and is later removed from there by some suitable means (not shown).

FIGURE 3 has, of course, been illustrated showing only the generally circular end plates and seal containing portions of vessel 4. In use a thick metal covering is secured over the drum 5 and bands 8 and 9. Lugs in the covering may be inserted thru holes 43 in the end plates and secured by nuts. Suitable conduits in the covering provide an inlet for steam into chamber 23.

In operation, the sheet material 10 may be fed directly into the nip between bands 8 and 9 or may be transported on a pervious band from some upstream web lay-down equipment or from a supply reel and fed into the nip of the bands 8 and 9; at which point, the web 10 is sandwiched therebetween and carried in this manner into the pressurized vessel 4. As the web 10 is transported into the chamber 24, it passes through the pressure seal 6 whereupon the sandwich arrangement is subjected to light pinning pressure. The seal allows only a negligible amount of steam to leak past along the interfaces of the bands; however, a laminar flow of steam passes through the fibrous structure of the sheet material 10 as shown by the arrows in FIGURE 6. This purges the air from the fiber interstices and heats the sheet material at an even rate as it enters the chamber.

Inside chamber 24 of the vessel 4, the sheet material becomes permeated with the saturated steam supplied to that chamber and is rapidly heated to bonding conditions. As the sheet material is transported through the vessel 4 between bands 8 and 9, the slight differential pressure between the chambers acts upon the upper band 8 causing it to exert a uniform contact pressure against the supporting surface of drum 5. This action pins the interposed sheet material and effectively restrains the fibers from excessive shrinkage during passage through the vessel. Upon entering the pressure seal 7 at the exit end, the fibers are covered with moisture and are in a heat-softened state which precludes handling without permanently damaging the fibrous structure. However, as the sheet material passes through the seal 7 to the atmosphere, the sudden decrease in pressure causes the moisture on the

fibers to flash into steam which exits through the perforated band 9 thereby tends to rapidly cool the web 10. As a result, additional downstream cooling and drying apparatus are not required and the finished sheet material can be handled almost immediately.

As will be apparent from the drawings, particularly FIGURE 1, the sheet material to be heat treated is maintained in a restrained condition, i.e. between the bands 8 and 9, a short time before it enters and after it leaves the pressure vessel. The latter is of special significance because it ensures that the material has cooled sufficiently to avoid any shrinkage after the restraint is removed. Only a very brief period of restraint outside the pressure vessel is required because the condensed vapor on the sheet material, being at a temperature above the atmospheric boiling point, rapidly vaporizes and exits through the perforated band, thus removing heat from the sheet material when the pressure is reduced to atmospheric. For most efficient utilization of this effect, it is desirable that the perforated band be in direct contact with the atmosphere after it passes through the exit opening of the pressure vessel.

Where process conditions involving low steam pressure and very light uniform contact pressures are dictated, it may be desirable to isolate completely any clamping effects on the web arising from belt tensions. Accordingly, in FIGURES 7 and 8, an alternate embodiment of the invention is shown which fulfills these requirements. In these figures, similar reference numerals designate similar parts referred to in FIGURES 1 through 6. The embodiment is different from that shown in FIGURE 2, in that a planar support is employed in place of a rotating drum on which the belt sandwich rests in the treatment zone. The support may be in the form of a series of closely spaced parallel rollers or a perforated moving conveyor but preferably is an inflexible stationary foraminous platen 70.

Framework 69, suitably attached to walls of vessel 4, supports the platen 70 so that surface 77 and belt 8 form a boundary between upper chamber 23 and lower chamber 24. The platen 70 is thus of a fixed location over which the belt sandwich is adapted to be advanced through the vessel 4. Means for recirculating the belts 8 and 9 are provided by rolls 71 and 72, which are coupled to an adjustable-speed electric motor (not shown). Belt tensioning and tracking are effected by tension rolls 73 and 74 and guide rolls 75 and 76, all of which are equipped with conventional means for adjustment.

As best shown in FIGURE 8, surface 77 is modified by an array of open grooves 78 and apertures 79 that convey steam from chamber 24 to the belt sandwich in a uniformly distributed manner. Although the groove arrangement shown extends generally parallel with the direction of belt travel, it will be apparent that any oblique angular relationship or curvilinear pattern may be established. Alternatively, steam may be distributed through a pattern of circular apertures or through a structure composed of a porous sintered material. The remaining portion of the surface 77, in rubbing contact with the belt 9, is treated to reduce the clamping effect of the steam pressure which is converted into frictional and high tensile forces in the belts. This may be accomplished in a number of ways such as texturing the surface by either mechanical brushing or chemical etching or preferably by an application of a thin layer of suitable material having a low coefficient of friction as, for instance, chrome plate. The surface may also be laminated with certain organic compositions capable of withstanding elevated temperatures and having self-lubricating properties, for example, polytetrafluoroethylene.

In alternate processes, the apparatus is capable of manufacturing a variety of products having special effects. For example, a dense highly compressed, parchment-like material may be produced by increasing the differential

clamping pressure between the chambers 23 and 24 and the net pinning force in the pressure seals 6 and 7. A product having a smooth, glazed finish may be readily achieved by processing a sheet material in contact with a smooth-surfaced band. A composite structure may be made such as fibers bonded to a film base wherein the film has a higher melting temperature than the fibrous component. A composite of a nonwoven sheet and film can also be prepared concurrently while effecting self-bonding of the nonwoven sheet. For example, an unbonded nonwoven sheet of oriented polypropylene filaments is placed next to the adhesive-coated side of a biaxially oriented polypropylene film. Branched polyethylene is a suitable thermoplastic adhesive. The layered structure is then passed through the apparatus to effect simultaneous self-bonding of the nonwoven sheet and activation of the adhesive coating on the film. The layered structure can be passed through the apparatus with either the nonwoven web or the film being in contact with the perforated band. In the former case, the steam permeates the nonwoven sheet structure as is the usual operating procedure for the apparatus. In the latter case, the steam contacts only the film since it is impervious and the entire steam pressure urges the film against the fibers. This effectively drives out the entrained air in the structure. When operating in this manner, it is possible to impart a glazed surface to the nonwoven web side of the composite by having it in contact with an impervious band having a smooth surface. Since many different embodiments of the invention may be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited except to the extent defined in the following claims.

What is claimed is:

1. Apparatus for heat treating a continuous length of sheet material comprising structure defining a pressure vessel having entrance and exit openings, first and second restraining means each providing an endless conveying surface for engaging, respectively, a major surface of said sheet material and effecting passage thereof in sandwich fashion into said entrance opening through said vessel and out said exit opening, said first restraining means comprising a substantially imperforate flexible band which divides said vessel into a first generally fluid tight chamber through which the sheet material passes and a second fluid tight chamber oppositely disposed of the first, means for establishing a heated fluid under pressure in said first chamber and means for establishing in said second chamber a fluid under a greater pressure than in said first chamber, said second restraining means providing a support for said sheet material and said imperforate flexible band within said vessel whereby the pressure differential between said chambers imparts restraining forces to the sheet material passing through said vessel, said second restraining means further being perforate whereby the heated fluid of said first chamber communicates with said sheet material in said vessel.

2. Apparatus of claim 1 wherein said second restraining means comprises a generally inflexible perforate body portion supporting an endless flexible perforate band which engages said sheet material within said vessel.

3. Apparatus of claim 2 wherein said generally inflexible perforate body portion comprises a rotatable drum.

4. Apparatus of claim 2 wherein said generally inflexible perforate body portion comprises a stationary platen.

5. Apparatus for heat treating continuous lengths of sheet material comprising wall means defining a pressure vessel having entrance and exit openings, within said vessel a supporting means having a generally inflexible foraminous surface, first and second endless flexible bands trained to run into said entrance opening upon the surface of said supporting means and out said exit opening, means for feeding said sheet material to be

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treated between said bands, said first endless band being substantially imperforate and cooperating with said wall means to separate said vessel into a first generally fluid tight chamber containing said supporting means and through which the sheet material passes and into a second fluid tight chamber oppositely disposed of the first, and means for establishing a heated fluid under pressure in said first chamber and means for establishing a fluid under pressure in said second chamber, said second endless flexible band further being perforated whereby the heated fluid of said first chamber communicates with said sheet material.

6. Apparatus of claim 5 wherein the face of said first endless flexible band which is in contact with said sheet material has an embossing pattern therein.

7. Apparatus of claim 5 wherein the face of said first endless flexible band comprises a smooth surface sheet.

8. Apparatus of claim 5 wherein the face of said supporting means comprises a rotatably mounted drum.

9. Apparatus of claim 5 wherein the face of said supporting means comprises a stationary platen.

10. Apparatus for heat treating continuous lengths of sheet material comprising structure defining a pressure vessel having entrance and exit openings, first and second endless flexible bands for engaging said sheet material therebetween and effecting passage of said sheet material in sandwich fashion into said entrance opening through said vessel and out said exit opening, said first endless band being substantially imperforate and, separating said vessel into a first generally fluid tight chamber having the sheet material disposed therein and a second fluid tight chamber oppositely disposed of the first, means for establishing a heated fluid under pressure in said first chamber and means for establishing in said second chamber a fluid under a greater pressure than in said first cham-

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ber, and a rotatable drum positioned within said first chamber and supporting the sandwich of said bands and sheet material during the major portion of its passage through said vessel, the surface of said drum and said second band being perforated whereby heated fluid in said first chamber can flow into contact with said sheet material.

11. Apparatus for heat treating continuous lengths of sheet material comprising structure defining a pressure vessel having entrance and exit openings, first and second endless flexible bands for engaging said sheet material therebetween and effecting passage of said sheet material in sandwich fashion into said entrance opening through said vessel and out said exit opening, said first endless band being substantially imperforate and separating said vessel into a first generally fluid tight chamber having the sheet material disposed therein and a second fluid tight chamber oppositely disposed of the first, means for establishing a heated fluid under pressure in said first chamber and means for establishing in said second chamber a fluid under a greater pressure than in said first chamber, and a stationary platen positioned within said first chamber and supporting the sandwich of said bands and sheet material during the major portion of its passage through said vessel, the surface of said platen and said second band being perforated whereby heated fluid in said first chamber can flow into contact with said sheet material.

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