Dec. 14, 1965 G. W. MISSON 3,223,443

HANDLING OF SHEET MATERIAL

Filed Oct. 17, 1963 2 Sheets-Sheet 1

FIG. 1

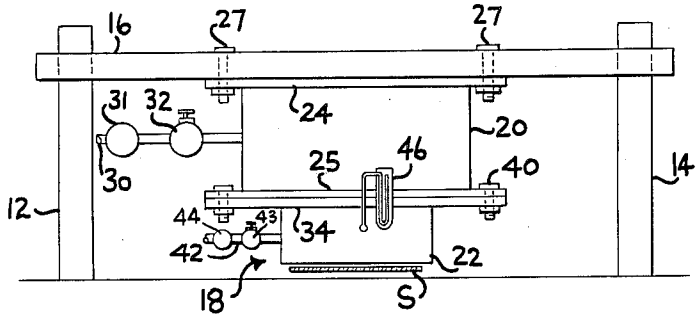


FIG. 3

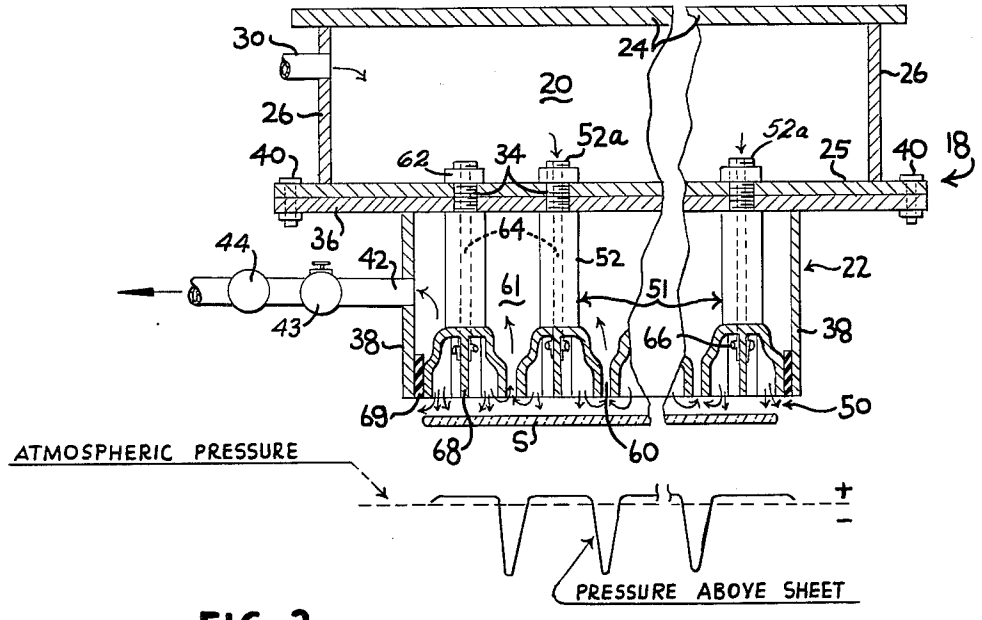
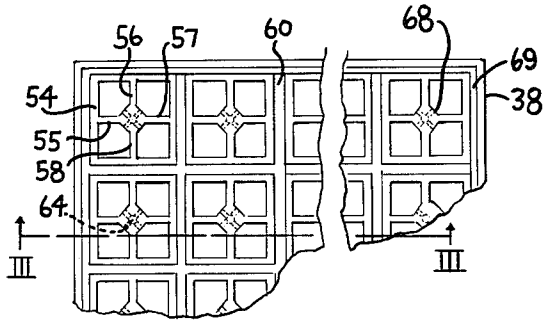


FIG. 2



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HANDLING OF SHEET MATERIAL

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FIG. 4

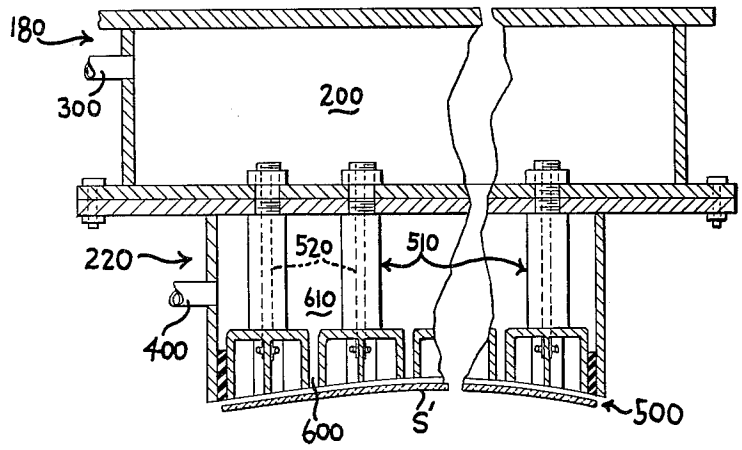


FIG. 5

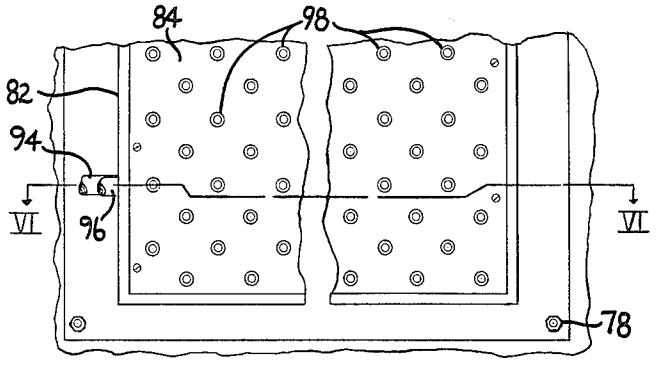
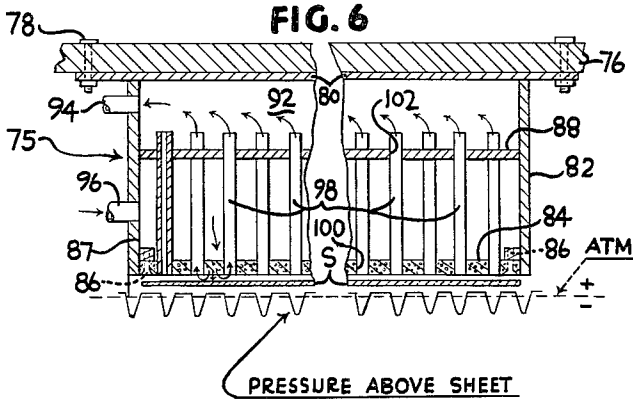


FIG. 6



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Patented Dec. 14, 1965

3,223,443

HANDLING OF SHEET MATERIAL

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Filed Oct. 17, 1963, Ser. No. 316,870
15 Claims. (Cl. 294—65)

This invention relates to the handling of sheet material and, more particularly, to methods and apparatus for supporting flat or curved glass sheets from above without physical contact. It is especially useful for supporting glass sheets heated to a deformation temperature without distorting or marring the sheets.

While it is known to support glass sheets from above, as with various known vacuum cup arrangments, the localized contact between the supported sheet and the perimeter or other structure forming the chamber characteristic of vacuum cups makes such an arrangement unacceptable for supporting readily deformable or easily marred sheet material such as glass at a temperature where the sheet may deform under its own weight or be marred by physical contact.

In the present invention, support is provided from above the sheet with a complete absence of contact between the supported sheet and any physical element. This may be accomplished by establishing pressure and exhaust zones adjacent the top surface of a sheet to be supported by flows of gas to and from the zone directly above the sheet. Control of the rates at which the gas is emitted and exhausted differentially establishes a net pressure directly above the sheet that is less than the ambient pressure by an amount equal to the weight of the sheet.

In accordance with a preferred embodiment of the invention, there is provided a modular arrangement of a plurality of evenly distributed gaseous pressure zones of uniform nominal pressure above a sheet of glass to be supported. Zones of lower pressure are created between the aforementioned pressure zones by exhausting the gas between the pressure zones to a vacuum source. By surrounding each pressure zone with side walls of an open bottomed chamber or module of a construction to be described, the pressure zones are isolated from the exhaust zones formed between walls of adjacent, but spaced, modules.

Gas flows from a reservoir under higher pressure into each pressure zone, being uniformly throttled between the reservoir and each zone to restrict the passage of gas between the two. Within each zone, gas entering from the reservoir is diffused after throttling so as to avoid creation of localized jets against a supported sheet and to equalize pressure and flow under normal conditions of operation. In operation, the rates of flow of gas from the reservoir to each modular pressure zone, and from a zone immediately above the supported sheet through the exhaust zones to the vacuum source, are controlled to provide an average clearance between the lower edges or outer termini of the module walls and the sheet being supported of at least about 0.001 inch, but not more than about 0.50 inch. An equilibrium condition may be attained because, as will be explained below in more detail, the positive pressure in each module increases as the gap between the outer termini of the module walls and the upper surface of the sheet diminishes in response to the evacuation of gas above the sheet through the exhaust zones. Depending upon the pressures and flow rates, an equilibrium position of the supported sheet is reached at a distance from the module walls where the positive pressure and the weight of the supported sheet balance the vacuum force.

In accordance with another embodiment of the invention, there is provided a continuous zone of uniform fluid pressure closely adjacent the upper surface of the sheet to be supported. Gas flows from a reservoir under higher pressure into such zone, being throttled by a porous material that forms a bottom cover or plate to the reservoir to diffuse and restrict the passage of gas between the reservoir and the continuous zone. Zones of lower pressure are created at locations interspersed in the continuous pressure zone and directly beneath unrestricted passageways, large with respect to the aforementioned pores, that open through the porous bottom plate. These passageways communicate between the pressure zone and a vacuum chamber connected to an evacuating mechanism.

Gas flows from the reservoir under higher pressure through the porous bottom plate to the zone immediately above the supported sheet. Gas is exhausted from said zone through the unrestricted exhaust passageways to create a reduction in pressure immediately above the supported sheet. The flows of gas are controlled to provide an average clearance between the porous bottom cover and the sheet being supported of at least about 0.001 inch but not more than about 0.50 inch. As in the previously described embodiment, the equilibrium condition is maintained because a reduction in space between the porous bottom cover and the upper surface of the supported sheet, in response to the evacuation of gas above the sheet, results in an increase in the pressure exerted by the gas emitted through the pores of the porous plate.

Advantageously, a glass sheet being supported and handled at elevated temperatures by a pressure control bed of a type herein contemplated may be maintained at the elevated temperature or its temperature may be otherwise controlled by burning a controlled admixture of gas and air, introducing the hot products of combustion to the reservoir or plenum chamber that supplies gas under pressure to the pressure zones and, if desired, supplementing the heat thus supplied to the glass by radiant heat from an independently controlled source or sources generally disposed on the side of the glass opposite the pressure control bed.

The attendant advantages of this invention and the various embodiments thereof will be readily appreciated as the same become better understood by reference to the following detailed description when considered in connection with the accompanying drawings in which:

FIG. 1 is a partly schematic, front elevation view illustrating a system for supporting a sheet of material from above in accordance with the present invention;

FIG. 2 is a partial bottom plan view, taken along the line 2—2 of FIG. 1, illustrating the modular arrangement for supporting a sheet of material from above in accordance with one embodiment of the present invention;

FIG. 3 is a sectional view, taken along the line 3—3 of FIG. 2, showing diagrammatically the flow of gas above a supported sheet of glass and presenting a diagrammatic graph in conjunction therewith;

FIG. 4 is a sectional view, similar to FIG. 3, showing a pressure control support bed having a curved lower surface for supporting a curved sheet of material;

FIG. 5 is a partial bottom plan view of another embodiment of a pressure control support bed for supporting sheet material from above without physical contact in accordance with the present invention; and

FIG. 6 is a sectional view taken along the line 6—6 of FIG. 5, showing diagrammatically the flow and exhaust of gas in the pressure control support bed and presenting a diagrammatic graph in conjunction therewith.

Referring to the drawings, FIGS. 1 to 3 illustrate a system advantageously employed for supporting a sheet of material, such as a sheet of glass S, in a substantially uniform manner without physical contact, in accordance with the teachings of this invention. Supported from a

framework of stanchions 12 and 14 and cross beams, one of which is shown at 16, is a pressure control support bed, indicated generally at 18. Included in the support bed is a plenum chamber 20 supported from cross beams 16 and a vacuum chamber 22 located beneath and supported by plenum chamber 20.

Plenum chamber 20 is formed from spaced upper and lower horizontal plates 24 and 25, respectively, and a vertical, continuous, peripheral side wall or walls 26 between the plates 24 and 25 and suitably fastened thereto, as by welds. Upper plate 24 is supported from cross beams 16 by bolts 27. An inlet pipe 30, including a pressure regulator and gauge 31 and a control valve 32, connects the plenum chamber 20 with a supply of gas under pressure. A plurality of openings 34 is provided in lower plate 25 to receive the stems of modularly arranged pressure outlets or "modules," later to be described.

Vacuum chamber 22 consists generally of a horizontal top plate 36 and a vertically disposed, continuous, peripheral wall or walls 38 suitably fastened to top plate 36, as by a weld. Top plate 36 is supported from bottom plate 25 of plenum chamber 20 by suitable fastening means, such as bolts 40. A conduit 42, including a pressure regulator and gauge 43 and control valve 44, connects the chamber formed by wall or walls 38 and top plate 36 with a vacuum source (not shown). In addition, a manometer 46 is connected to vacuum chamber 22 to provide an accurate pressure measurement.

Within the confines of peripheral wall 38 of vacuum chamber 22 is a flat bed 50 of modules 51 in spaced but close juxtaposition, each to the other, and arrangement geometrically like a mosaic. In the embodiment illustrated, all modules 51 have their lower termini of rectangular configuration and lying in a common plane or generative surface. Each module 51 has a stem 52 of smaller cross-sectional area than the lower terminus and each stem opens into plenum chamber 20 positioned above the bed 50 and acting as a support therefor. Preferably, the modules are smaller in cross-section just above the lower termini to more adequately facilitate the flow of exhaust gas.

As best shown in FIG. 2, each module is substantially enclosed by a chamber wall 54 and subdivided by partitioning walls 55, 56, 57 and 58 into four chambers or submodules. Each module is separated from the next adjacent by an exhaust zone 60. Exhaust zone 60 widens into a larger exhaust channel 61 surrounding module stems 52 within vacuum chamber 22. Conduit 42 is in direct communication with exhaust channel 61 and supporting vacuum can be applied above a glass sheet through the exhaust zones 60 between each module.

Each module stem 52 includes a threaded, terminal portion 52*a* of smaller diameter than the stem proper that fits within openings 34 in plates 25 and 36. A nut 62, in threaded engagement with stem portion 52*a*, secures each module 51 to plates 25 and 36. Each module stem 52 is hollow, having a conduit 64 providing a channel of communication between the interior of plenum chamber 20 and openings or orifices 66 communicating with the subchambers of modules 51.

The outer terminus, i.e., the lower periphery of chamber wall 54 of each module 51, defines a zone of substantially uniform pressure (a profile of which is diagrammatically shown in FIG. 3) above the underlying supported sheet. Pressure is exerted by gas supplied to each module from the supporting plenum chamber 20 by way of the hollow module supporting stem 52. Bores or orifices 66, in a central portion 68 of each module 51 formed by the intersection of dividing walls 55 to 58, provide a gas inlet to each subchamber of the module and also function to diffuse the gas by changing the direction of flow to a horizontal direction as the gas escapes and expands into the module chamber. The orifices 66 are disposed to prevent direct impingement of pressurized gaseous fluid against the upper surface of the support sheet so as to prevent dimpling of the material (for example, where glass heated to a deformation temperature is being supported) from the velocity pressure of a localized jet of gas. By feeding the gas into the subchambers of the modules through a conduit or orifice that is smaller in cross-section than the module, the gas diffuses into the gas of the chamber, producing a diffused flow, thus ensuring uniform pressure across the lower edges of the module.

Most advantageously, the relatively small size of orifices 66 provides a drop in gas pressure from the interior of plenum 20 to the interior of the subchambers of modules 51, and in so doing, performs three important functions: First, it prevents modules that are not directly overlying the supported sheet of material from allowing the rapid escape of gas from the common plenum, which would reduce the pressure in the plenum and, hence, in the modules overlying the sheet; second, it prevents variations of load upon the modules, as might be experienced by variations in the vacuum applied to the glass through exhaust zones 60 or from other external forces, from sensibly affecting the flow of gas from the plenum into the module; and third, it diminishes the effect of any slight variations in plenum pressure upon the pressure within the module. With this arrangement, the gap between the lower terminus of the module walls and the upper surface of the supported sheet becomes self-adjusting to a substantially uniform size about the entire periphery of each module. The size of the gap is a function of the reduced pressure above the glass sheet from the vacuum source, as applied through exhaust zones 60, the positive pressure applied through the modules, and the weight of the sheet being supported. The gap is self-adjusting because a decrease in flow of gas from the modules due to a decrease in the gap results in a pressure build-up within the module that resists any force tending to decrease the gap. Because the pressure within the module automatically increases in magnitude to as great as the plenum pressure as the gap become extremely small, contact between the sheet being supported and the modules is prevented under all ordinary circumstances by maintaining a sufficiently high plenum pressure.

Supply of the gas to the modules is effected under conditions such that the ratio of pressure drop between the plenum chamber or gas reservoir and the modules to the pressure drop between the modules overlying a supported glass sheet and the exhaust spaces is held high, being above 2, preferably above 3 and in most cases above 5.

The rate at which the pressure within the module builds up with a decrease in the gap is a function of the rate of gas flow into the module and the volume of gas in the module. Hence, the orifice must not be so small for a given plenum pressure as to restrict the flow of gas into each module to the extent that excessive time is required to increase the pressure in response to a decrease in the gap between the module and the upper surface of the supported sheet. In most cases, sufficient gas should enter the chamber within not more than 1 second, generally less than 0.1 second, and preferably almost instantaneously to supply the required increased pressure necessary to prevent the glass from touching the module edge in response to the evacuation of gas above the supported sheet through the exhaust zone. Modules of small volume are more responsive for this purpose than are larger modules for a given flow rate. Generally, the modules herein contemplated have a volume below 25 cubic inches, preferably not over about 10 cubic inches, and most desirably less than about 2 cubic inches. By subdividing each module into four separate chambers, not only is the volume of gas that affects the time of response diminished, but also each cavity functions in effect as a submodule, and the pressure profile across the entire internal width of each module 51 is substantially flat with the advantage

that positive pressure is provided when any one submodule is directly above a supported sheet, even though the entire module does not overlie the sheet.

It should be understood, of course, that the modules need not be subdivided and may be of any convenient size as long as they are relatively small with respect to the area of the sheet being supported. In addition, the modules need not be square but may be of other geometric or free-form shape, for example, round or triangular. The module depth is not critical as long as it is sufficient to provide adequate diffusion of the gas and is not so deep as to increase the volume of gas to an extent that response time is too great.

Preferably, a rubber gasket or sealing member **69** is located between peripheral walls **38** of vacuum chamber **22** and the peripherally located module walls **54** of the module bed **50**. This minimizes or eliminates the flow of gas through exhaust zones that do not lie directly over the sheet to be supported and thereby increases the efficiency of the system. It is not necessary, however, to so seal the periphery of the bed, nor to tailor the bed to the size and shape of the sheet to be supported.

In operation, a sheet of material, such as a sheet of hot glass at or near its deformation temperature and subject to marring and distortion through physical contact, is located closely adjacent the module bed **50** in general alignment therewith and spaced from the lower terminus of the chamber walls **54** of modules **51** by a distance of approximately 0.10 inch. A vacuum is applied through conduit **42** to vacuum chamber **22** and a positive pressure is applied at the lower terminus of modules **51** by the flow of gas from plenum chamber **20** through conduits **64** in module stems **52** and through openings or orifices **66** of modules **51**. The evacuation of gas from directly above the supported sheet through the network of exhaust zones **60** and the exhaust channel **61** reduces the pressure above the sheet to be supported, and when this reduction in pressure is of a magnitude equal to or greater than the weight of the sheet, the ambient pressure provides support. The rate at which gas is evacuated from above the supported sheet is of a magnitude sufficient to cause the sheet of material to be lifted. As the sheet moves closer to the lower termini of modules **51**, the flow of gas from the modules is decreased and the pressure within the modules increases until it overcomes any further tendency of the sheet to move upwardly. Thus, the positive pressure and the weight of the glass balance the vacuum force and equilibrium condition is reached. It has been found that best results are obtained when the rate of gas flow to and from the zone immediately above the sheet to be supported is controlled to support the sheet in an equilibrium condition at a distance between 0.10 and 0.001 inch from the lower or outer terminus of the modules **51**.

Where sheets of material at an elevated temperature are to be supported and handled, for example, where sheets of glass heated to a deformation temperature are to be supported in the above-described manner, the flow of gas to modules **51** under positive pressure and at an elevated temperature may be advantageously obtained by using one or more direct-fired, air heater type, excess air burners of a standard type well known in the art to supply products of combustion to plenum chamber **20**. The combustion of a fuel gas and air in an adjacent combustion chamber (not shown) or within the plenum to produce products of combustion provides sufficient plenum pressure to supply the modules with heated gas of a uniform temperature and pressure. Adequate control of pressure and temperature is provided by correlating the rates of input of air and fuel to the burners. To supply enough gas to effect the desired positive pressure under normal conditions, an excess of air (usually 50 percent or more in excess) over that required for the combustion of the fuel gas is used. The supply of gas may be varied to change the pressure in the plenum.

Pressure profiles across the lower or outer terminus of a module may be determined in the following manner: A pressure sensing plate having a small hole therethrough is positioned beneath a module and spaced from the lower terminus thereof a distance corresponding to the distance therefrom of a supported sheet, e.g., 0.010 inch. A pressure transducer is connected to the sensing hole, and the electrical output of the pressure transducer is connected to a recorder that will graph pressure variations on one axis and displacement of the pressure sensing plate on the other axis. The pressure transducer controls the displacement of the recording device along, e.g., the Y-axis of the graph. A potentiometer, the shaft of which is rotated by relative horizontal movement between the sensing plate and the module, translates such movement into an electrical signal that controls the displacement of the recording device along the other axis of the graph.

As is shown by the pressure profile in FIG. 3 of the drawings, a positive pressure, indicated by that portion of the solid line curve above the dotted line indicating atmospheric pressure, is produced directly beneath each module **51**. A negative pressure (i.e., less than ambient pressure) is produced directly above the supported sheet in those areas beneath exhaust zones **60**. The magnitude of the negative pressure and the area over which it is applied is of a magnitude sufficiently great to balance the weight of the sheet to be supported plus the positive pressure exerted by the flow of gas from the modules.

There is shown in FIG. 4 a pressure control support bed **180** similar to support bed **18** of FIGS. 1 to 3, but having a curved bed of modules **500** for supporting and handling curved sheets of material such as a sheet of glass that has been heated to a deformation temperature and formed to a curved shape, such as a cylindrical or compound bent shape. A plenum chamber **200**, supporting a plurality of modules **510**, supplies gas under pressure through hollow stems **520** of modules **510** to a zone directly above a curved sheet of material S' to be supported. Plenum chamber **200** is supplied with gas under pressure through an inlet pipe **300**. Vacuum chamber **220** surrounds the bed **500** of modules **510** to enclose an exhaust channel **610** about module stems **520** and in communication through a conduit **420** with a vacuum source, not shown. Exhaust zones **600** are formed by the space between adjacent modules **510** and are in direct communication with the exhaust channel **610**.

The distances of the modules **510** from the plenum chamber **200** are selectively and progressively changed along the length and across the width of the module bed **500** by reducing the depth of the module cavities in varying degrees to define, by the lower termini of the modules, a curved surface. By selecting the curved surface generated by the outer termini of modules **510** to be in substantial conformity with the curvature of the sheet to be supported, the pressure control support bed **180** functions in the same manner as the support bed **18** described above.

With reference now to FIGS. 5 and 6, there is shown another embodiment of apparatus for supporting a sheet of material without physically contacting the sheet. A pressure control support bed, indicated generally at **75**, is suitably suspended from a support member **76** by fastening means such as bolts **78**. The pressure control support bed **75** consists of a large enclosure formed by a top horizontal plate **80**, a vertically disposed, continuous, peripheral wall or walls **82** fastened to top plate **80**, as by a welded intersection, and a horizontal porous bottom plate **84** suitably fastened to peripheral wall **82**, as by machine screws **86** in threaded engagement with lugs **87** of walls **82**. The enclosed chamber defined by top plate **80**, side walls **82**, and porous bottom plate **84** is subdivided horizontally into two chambers by dividing plate **88**. Dividing plate **88** divides pressure control support bed **75** into a lower pressure or plenum chamber **90** and an upper vacuum chamber **92**. Conduit **94** connects

vacuum chamber **92** with a vacuum source, not shown. Inlet pipe **96** supplies gas under pressure from a source (not shown) to plenum chamber **90**.

Thin-walled tubes **98** are located within holes **100** of porous plate **84** and extend through plenum chamber **90** in a substantially vertical direction through holes **102** in dividing plate **88**. Tubes **98** are flush with the bottom surface of porous plate **84** and are very large in diameter with respect to the diameter or size of the pores in plate **84**.

With this construction, tubes **98** provide a plurality of conduits communicating between the vacuum chamber **92** and a zone immediately below porous plate **84** and above the sheet S to be supported. Gas under pressure is supplied through the small openings or pores of the plate **84** to the zone immediately beneath porous plate **84** and above supported sheet S and is exhausted through tubes **98**.

In a manner similar to that explained in connection with the previously described embodiments, the withdrawal of gas from the zone immediately above the sheet to be supported through tubes **98** reduces the pressure above the sheet to result in the upward movement and support of the sheet by ambient pressure. As the sheet approaches the porous plate **84**, the flow of gas escaping through the pores of plate **84** from plenum chamber **90** decreases as the distance between the top surface of sheet S and the bottom surface of porous plate **84** decreases, and the pressure above the plate becomes greater. In this manner, contact between porous plate **84** and sheet S is prevented. The pressure profile illustrated in FIG. 6 indicates, in the same manner as explained in connection with the graph of FIG. 3, the relative magnitudes and locations of the pressure variations caused by the controlled flow of gas to and from the zone immediately above the supported sheet.

Where hot sheets of material, such as sheets of glass heated to a deformation temperature, are to be supported, the support bed **75** should be constructed of heat resistant materials. For example, the porous bottom plate **84** may satisfactorily be constructed of sintered stainless steel particles, granular silicon carbide, or finely divided alumina grog with a binder. The thin-walled exhaust tubes **98** may be constructed of the same or similar heat-resistant materials, but, of course, are not porous. The desired flow and pressure drop of the gas through the porous plate may be controlled by the size of the pores in porous plate **84**. This, in turn, may conveniently be controlled by the particle size of the materials of which the plate is formed. For best results, it has been found that the pore size should be maintained small (the average distance across the pores being preferably between about 0.0002 and 0.025 inch and the void content of the material being about 50 percent) so that the flow of gas is restricted and the pressure from the plenum chamber is reduced by a factor of at least about 1.5, and preferably of above 5. The diameter of exhaust tubes **98** should be large with respect to the pores and may vary from as small as 0.050 inch to as large as 1 inch or greater, depending upon the number used, the area of the support zone, and the length of the tubes. In operation, the rate of flow of gas from the plenum chamber **90** through the porous plate **84** to the zone immediately above the supported sheet S, as well as the exhaust pressure, and hence the flow of gas from the zone above sheet S through tubes **98**, are maintained at levels to produce an average clearance between the lower surface of the porous plate and the upper surface of the supported sheet of not less than 0.001 inch and ordinarily not greater than 0.10 inch.

It will be understood that porous plate **84** need not be planar but may be curved, either cylindrically or in a compound configuration to facilitate the support and handling of curved sheets, such as glass sheets heated to deformation temperature and bent to a desired configuration. It will also be understood that where sheets of material are to be handled at an elevated temperature, the gas emitted through porous plate **84** from plenum chamber **90** may be preheated or may be products of combustion supplied in the manner above described in connection with the other embodiments.

The following are examples, by way of illustration only, of preferred modes of operation of the invention disclosed herein as applied to the support and handling of a glass sheet:

Example I

A sheet of glass 4 inches square by ⅛ inch thick and weighing 0.18 ounce per square inch is placed by hand adjacent the bottom surfaces of modules of a horizontally disposed, square bed of 9 modules constructed as shown in FIGS. 1 to 3 and described above. The lower terminus of each module is 1⅜ inches square, outside diameter, with walls of 1/16 inch in thickness. The modules are spaced from each other and located on 1½ inch centers. This provides an effective pressure area above the 4-inch square sample of 6.61 square inches (considering only those module subdivisions completely overlying the glass) and an exhaust area of 1.937 square inches.

Air under pressure is supplied to plenum chamber **20** to provide a plenum pressure of 6 ounces per square inch gauge. A vacuum was applied to conduit **42** of vacuum chamber **22** to reduce the pressure in vacuum chamber **22** by 1.8 ounces per square inch gauge (3⅛ inches of water column). Orifices **66** reduce the pressure of plenum chamber **20** by a factor of approximately **60**, and gas is emitted from modules **51** at a flow of approximately 1¾ standard cubic feet per minute per module.

The glass sheet is stably supported beneath bed **50** at a distance of approximately 0.005 inch from the lower termini of the modules.

Example II

A sheet of glass as described in Example I is supported in the manner described therein with the following differences:

The glass sheet is preheated to a temprature of approximately 1000° F. and initially supported beneath module bed **50** on a flat, uniform, preheated surface. Hot products of combustion produced by burning natural gas and air in proportions by volume of approximately 1 to 36, respectively, which includes 260 percent excess air over that required to provide complete combustion. Natural gas is provided at a rate of approximately 60 cubic feet per hour per square foot of bed. The products of combustion are introduced to the plenum chamber, producing therein a pressure of approximately 6 ounces per square inch gauge.

The physical support for the glass sheet is removed and the glass is supported beneath module bed **50** a distance of approximately 0.005 inch. Radiant heat is then applied to the bottom surface of the supported glass sheet and the temperature of the glass is maintained at substantially 1000° F. without marring or deformation.

Example III

A sheet of glass 4 inches square and ⅛ inch thick is supported beneath a pressure control bed of the type disclosed in FIGS. 5 and 6 and described above. Hot products of combustion are supplied to plenum chamber **90** in the same manner described in connection with Example II at a flow rate of approximately 50 cubic feet per minute per square foot of bed area to produce a plenum pressure of 35 ounces per square inch gauge. The porous plate forming the bottom of plenum chamber **90** is sintered stainless steel. The average distance across the pores is between 0.002 and 0.025 inch and the void content is about 50 percent. The plate reduces the pressure of the gas flowing therethrough by a factor of about 14. Tubes **98** provide exhaust passages 0.060 inch in diameter and overlie approximately 13 percent of the supported glass area.

A reduced pressure of 6 ounces per square inch gauge is established in vacuum chamber **92**.

The sheet of glass is stably supported beneath the porous plate 84 a distance of approximately 0.005 inch. Radiant heat is then applied beneath the supported sheet and the temperature of the glass is maintained at approximately 1000° F. without objectionable marring or deformation.

It will be understood that while in the foregoing disclosure certain preferred embodiments of the invention have been disclosed, numerous modifications or alterations may be made therein without departing from the spirit and scope of the invention as set forth in the appended claims.

I claim:

1. A method of supporting a sheet of glass which comprises supplying gas under pressure greater than ambient pressure to spaced pressure zones above a sheet of glass and withdrawing gas at a pressure less than ambient pressure from exhaust zones intermediate said spaced pressure zones at rates that differentially establish a pressure above said sheet of glass of a magnitude sufficiently less than ambient pressure to cause the weight of said sheet to be supported by the ambient pressure.

2. A method of supporting a sheet of hot, deformable glass which comprises establishing a plurality of spaced gas zones, each enclosed by side walls and exerting a downward positive pressure upon the upper surface of a sheet of hot glass, establishing a source of gas under a pressure greater than that in said spaced gas zones, feeding gas from said source to said spaced gas zones, reducing the pressure of said gas as it is fed to said spaced gas zones, exhausting gas from said spaced gas zones across the enclosing side walls thereof and from above said sheet to zones of reduced pressure between said spaced gas zones, and correlating the rates of said feeding and exhausting of gas to differentially establish a pressure above said sheet sufficiently lower than ambient pressure to cause said sheet to be supported an average distance of at least about 0.001 inch but not more than about 0.50 inch below the lower edges of said side walls.

3. The method of claim 2 further including the step of maintaining a pressure drop between said source and said spaced gas zones overlying the sheet of hot glass at least two times the pressure drop between said spaced gas zones overlying the sheet and said zones of reduced pressure.

4. A method of supporting glass which comprises emitting a flow of gas under pressure from a plurality of outlets closely adjacent an upper surface of a sheet of glass, exhausting gas from adjacent the upper surface of said sheet of glass through zones of negative pressure interspersed among said plurality of outlets and controlling the rate at which the gas is emitted and the rate at which the gas is exhausted so as to create a reduction in pressure adjacent the top surface of said sheet relative to ambient pressure beneath said sheet substantially equal to the unit area weight of said sheet.

5. A method of supporting flat or curved sheet material which comprises locating said sheet beneath but spaced from a plurality of adjacent outlets for discharging and withdrawing gas, discharging gas from some of said orifices to a zone directly above the sheet and beneath the outlets and withdrawing gas from said zone through other of said orifices at a rate sufficiently greater than the rate at which gas is discharged into said zone to establish a pressure in said zone that is less than ambient pressure by an amount equal in magnitude to the unit area weight of the sheet, the pressure of said zone increasing in response to a reduction in the spacing between the sheet and the outlets, whereby the sheet is maintained in a position spaced from and beneath the said outlets.

6. A method of supporting sheet material, which comprises locating the sheet beneath and spaced from a plurality of spaced orifices comprising a pressure control bed, discharging gas from some of said orifices in the bed and withdrawing gas through other of said orifices interspersed throughout the bed at rates that establish above the sheet a net pressure that is less than the ambient pressure by an amount equal to the unit weight of the sheet when the upper surface of the sheet is at a distance from the bed of between 0.001 an 0.10 inch and at rates that cause the net pressure above the sheet to increase in response to a reduction in the distance between the bed and the upper surface of the sheet and to decrease in response to an increase in distance between the bed and the upper surface of the sheet.

7. A method of supporting flat or curved sheet material, which comprises establishing confined pressure zones above a sheet to be supported, supplying gas under pressure to said confined pressure zones adjacent the top surface of said sheet, withdrawing gas from above the top surface of said sheet between said confined zones at a greater rate than the gas is supplied to establish a pressure above the sheet that is less than the pressure below the sheet by an amount equal to the unit weight of the sheet and varying the pressure above the sheet in response to movement of said sheet toward and away from said confined pressure zones.

8. A method of supporting flat or curved sheet material, which comprises locating said sheet beneath and spaced from a plurality of orifices, supplying gas under pressure through some of said orifices to a zone immediately above said sheet, withdrawing gas from said zone through other of said orifices at a rate great enough to reduce the pressure above the sheet to an extent that the sheet is supported closely adjacent said orifices by the ambient pressure, and varying the magnitude of pressure above the sheet and beneath the orifices in response to changes of the spacing between the sheet and said orifices.

9. Apparatus for supporting a sheet of material from above and without contact therewith, which comprises a plenum chamber; a porous, gas-permeable plate forming the bottom of said plenum chamber; means to supply gas under pressure to said plenum chamber; a vacuum chamber; and passageways, large in diameter with respect to the pores of said plate, opening through said plate and communicating between a zone immediately beneath the gas-permeable plate and said vacuum chamber.

10. A method of supplying support to a sheet which comprises disposing a portion of said sheet beneath a low pressure zone which is at sub-atmospheric pressure and is separated by a boundary from a higher pressure zone, supplying gas under pressure to the high pressure zone to cause flow of gas between said boundary and the glass from the high pressure zone to the low pressure zone, withdrawing gas from the low pressure zone and correlating the rate of said gas withdrawn with the rate of gas supply to maintain a lower pressure adjacent said portion or top surface of said sheet and the ambient pressure beneath the same portion of said sheet.

11. The process of claim 10 wherein the sheet is heated by supplying hot gas to said higher pressure zone and heating the glass from a heat source beneath said glass.

12. Apparatus for supporting a sheet of material from above, and without contact therewith, which comprises a plenum chamber, a vacuum chamber disposed beneath said plenum chamber, means to supply gas under pressure to said plenum chamber, means to provide a vacuum to said vacuum chamber, a plurality of modules positioned within said vacuum chamber and connected to said plenum chamber, each of said modules comprising an elongated stem having a conduit, a terminal open bottom chamber portion having peripheral walls, each of said module stem conduits having openings directed into said open bottom chamber, said module stem conduit opening into the interior of said plenum chamber and providing a means of gas communication between the interior of said plenum chamber and the openings within said open bottom module chamber, said modules arranged geometrically like a

mosaic, said lower chamber walls forming boundaries between zones of gas supply and zones of gas exhaust, said lower chamber wall peripheries froming a common generative surface for the bottom of said vacuum chamber.

13. Apparatus for supporting a sheet of material from above, and without contact therewith, which comprises a plenum chamber, a vacuum chamber having peripheral walls disposed beneath said plenum chamber, means to supply gas under pressure to said plenum chamber, means to provide a vacuum to said vacuum chamber, a plurality of modules positioned within said vacuum chamber peripheral walls and connected to said plenum chamber, each of said modules comprising an elongated stem having a conduit, a terminal open bottom chamber portion having peripheral walls, each of said module chambers having partitions dividing said chamber into subchambers, said module stem conduit having openings directed into said subchambers, said module stem conduit opening into the interior of said plenum chamber and providing a means of gas communication between the interior of said plenum chamber and the openings within said subchambers, said modules arranged geometrically like a mosaic, said lower chamber walls forming boundaries between zones of gas supply and zones of gas exhaust, said lower chamber wall peripheries forming a common generative surface for the bottom of said vacuum chamber.

14. The apparatus of claim 13 wherein each module open bottom chamber has four partitions, defining four subchambers therein.

15. Apparatus for supporting a sheet of material from above, and without contact therewith, which comprises a plenum chamber having openings in a bottom portion thereof, a vacuum chamber having peripheral walls disposed beneath said plenum chamber, means to supply gas under pressure to said plenum chamber, means to provide a vacuum source to said vacuum chamber, a plurality of modules disposed within said vacuum chamber, a module having a stem, an open bottom chamber having peripheral walls, said stem having a conduit, terminating in orifices disposed within said open bottom chamber, said module conduits connected to said openings in said plenum chamber bottom surface for providing means of gas communication between the interior of said plenum chamber and said module open bottom chamber, the lower peripheries of said chamber walls separating zones of gas supply from zones of gas exhaust, said open bottom chamber orifices being smaller in cross-section than said stem conduit so as to reduce the gas pressure between said plenum and said open bottom chamber, said orifices disposed within said open bottom chamber so as to provide a flow of gas substantially parallel to the surface of said sheet material, said modules being arranged geometrically like a mosaic with their lower chamber peripheries forming a common generative surface disposed within the bottom of said vacuum chamber, so that gas under pressure flows from said gas supply zones to said gas exhaust zones.

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