United States Patent

[11] 3,554,242

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[54] **METHOD OF FORMING A SCREEN**
10 Claims, 25 Drawing Figs.

[52] U.S. Cl. 140/107, 29/163.5
[51] Int. Cl. B21f 27/18
[50] Field of Search 55/36, 159, 199, 521, 529; 29/475, 480, 163.5, 419; 140/107, 108; 72/379, 384

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ABSTRACT: Methods of fabricating hollow concavo-convex shapes from a flat blank by pleating and then forming the blank. The pleated, rolled blank is not placed in a die cavity. It is only expanded into a spherical shape. Liquid-gas separator screens produced by the forming methods in such manner that a predetermined screen pore size is maintained whereby the screens exhibit a meniscus liquid gas separating action under a normal pressure drop across the screens.

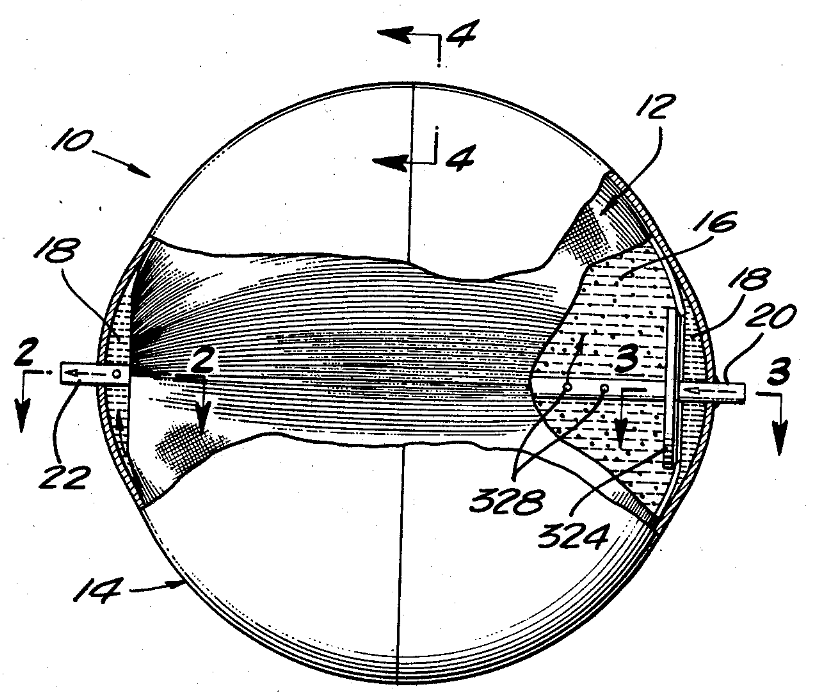


FIG. 1.

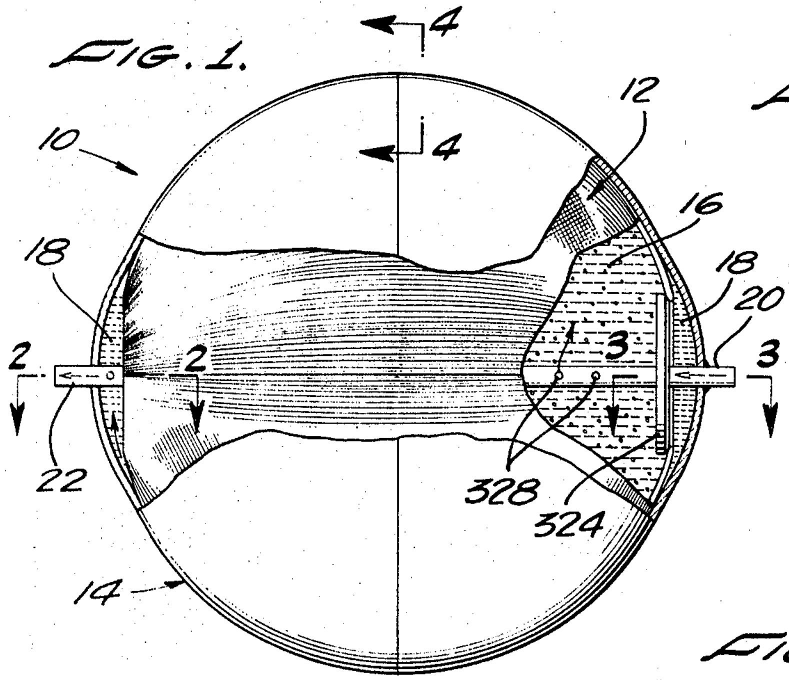


FIG. 2.

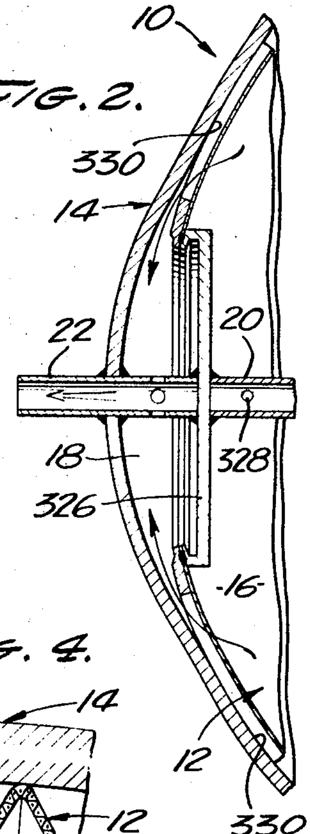


FIG. 3.

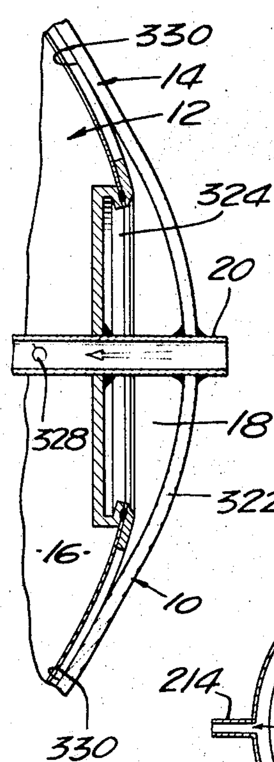
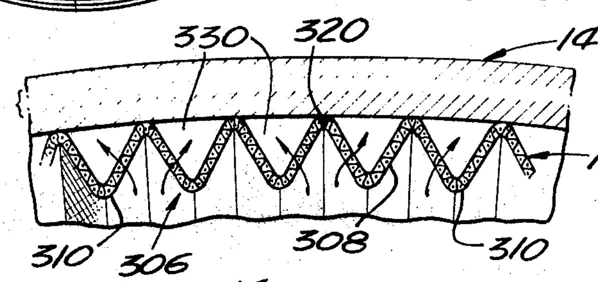


FIG. 4.



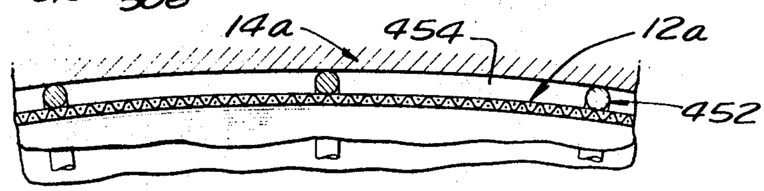


FIG. 6.

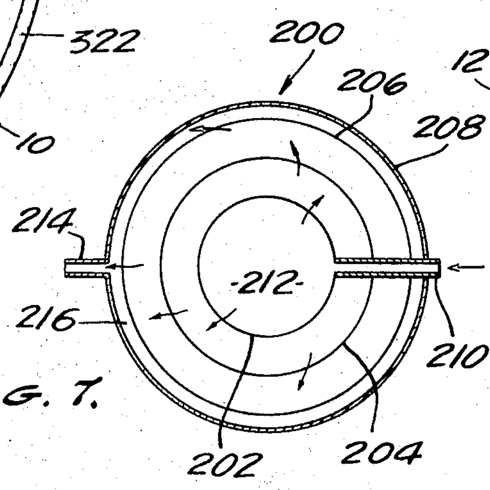


FIG. 7.

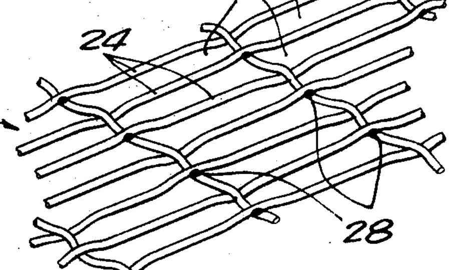


FIG. 5.

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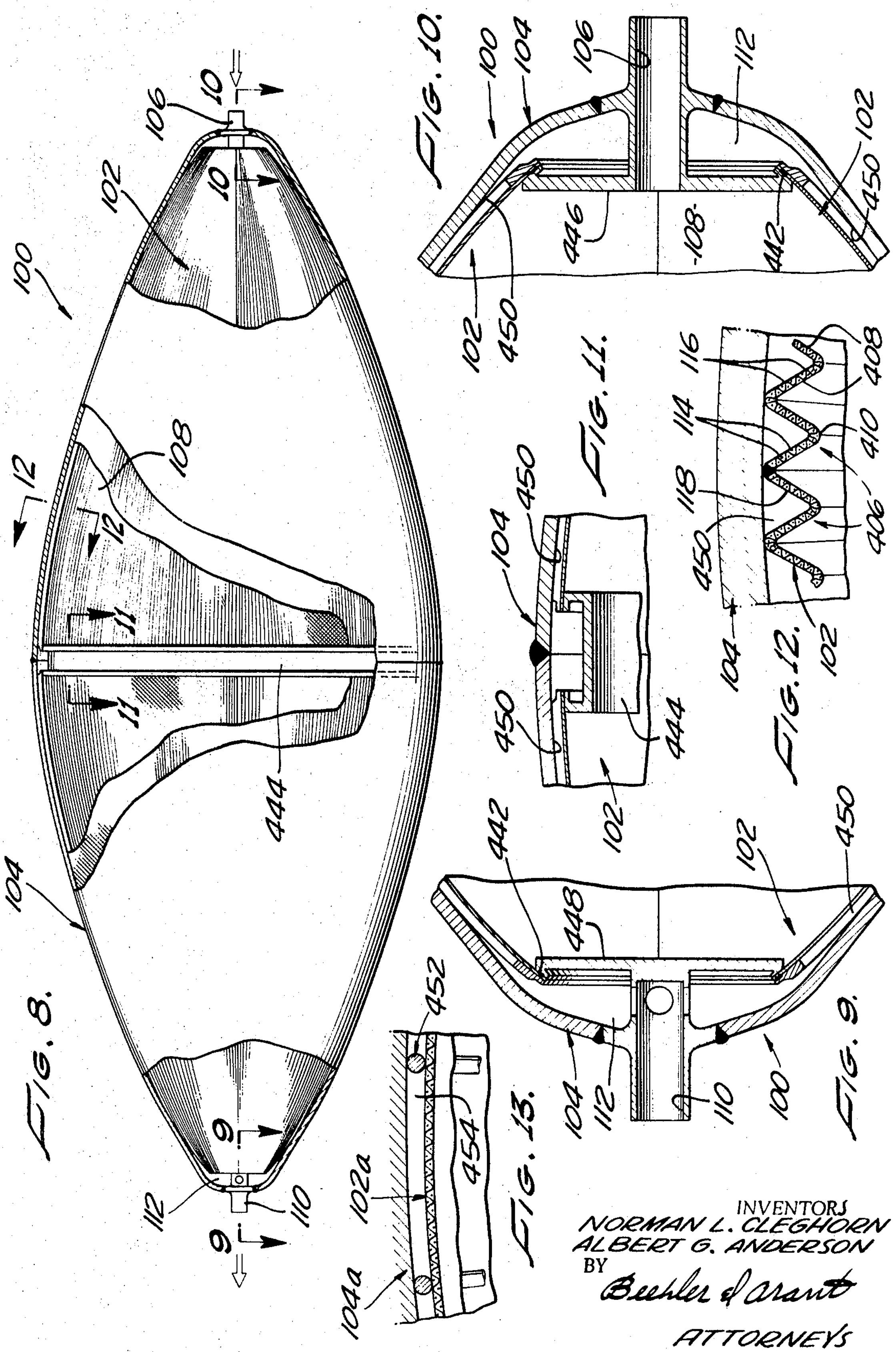

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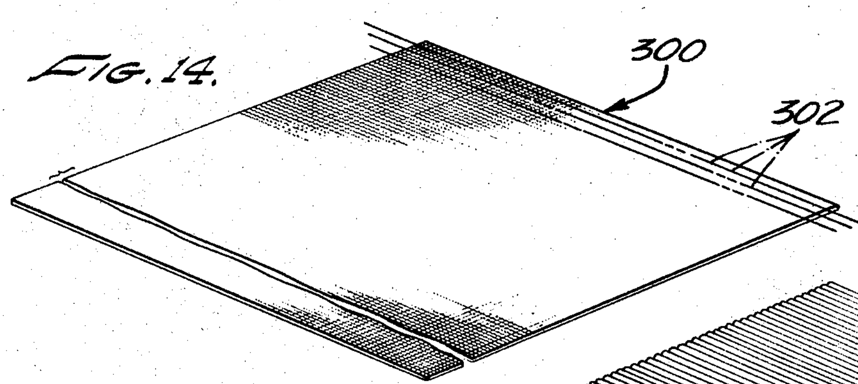
FIG. 14.



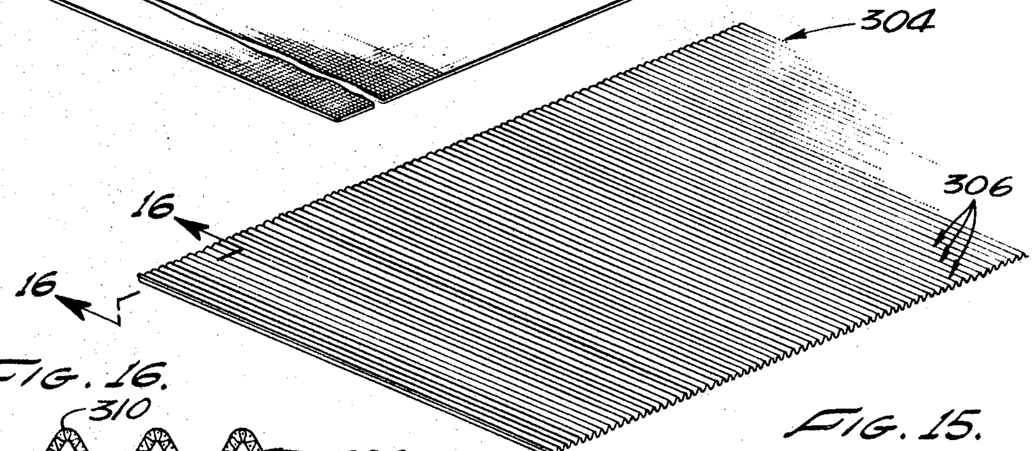
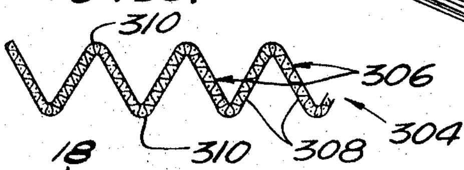


FIG. 15.

FIG. 16.



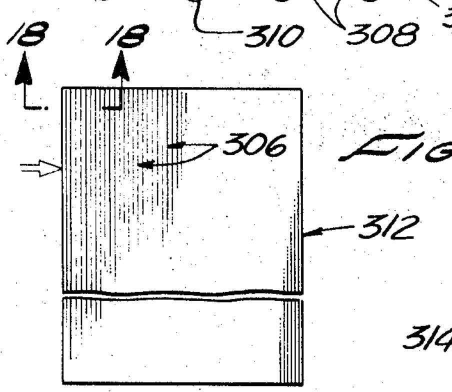
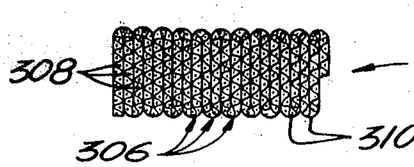
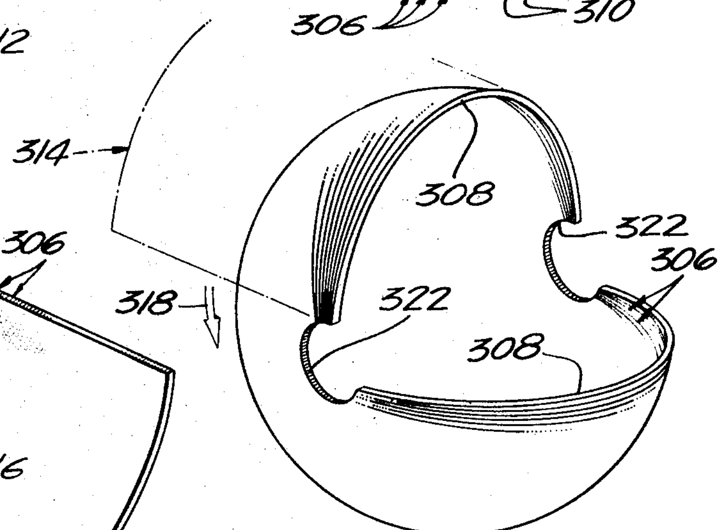


FIG. 17.

FIG. 18.





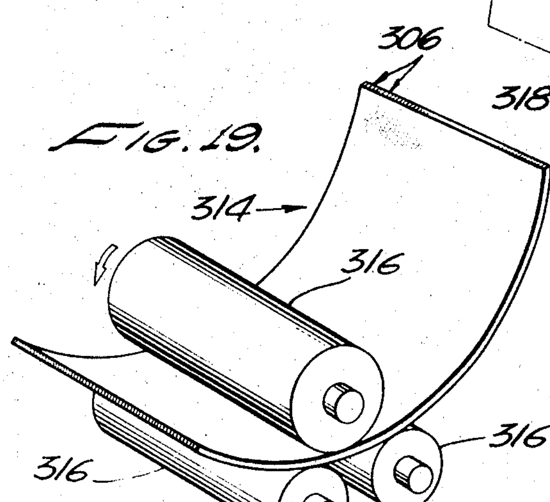


FIG. 19.

FIG. 20.

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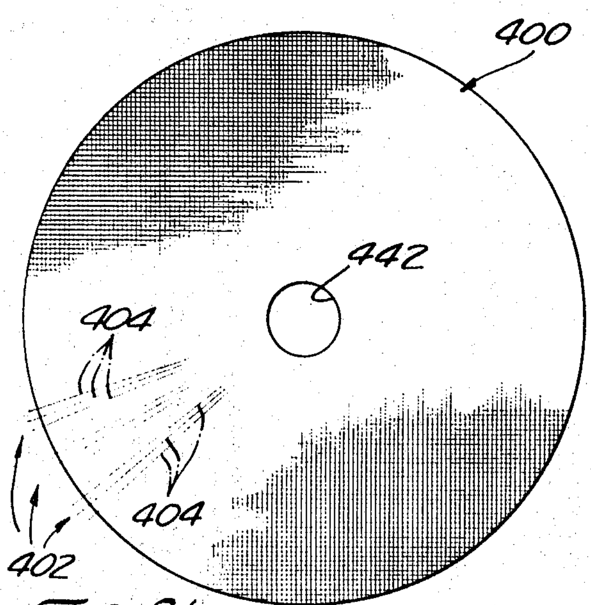

FIG. 21.

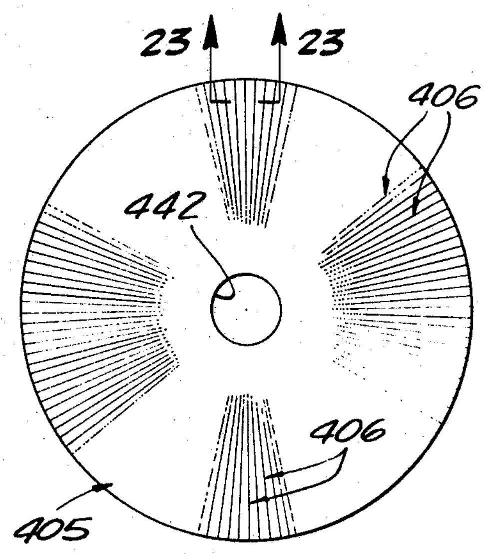

FIG. 22.

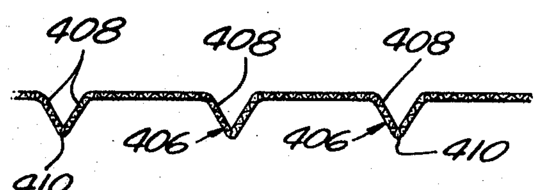

FIG. 23.

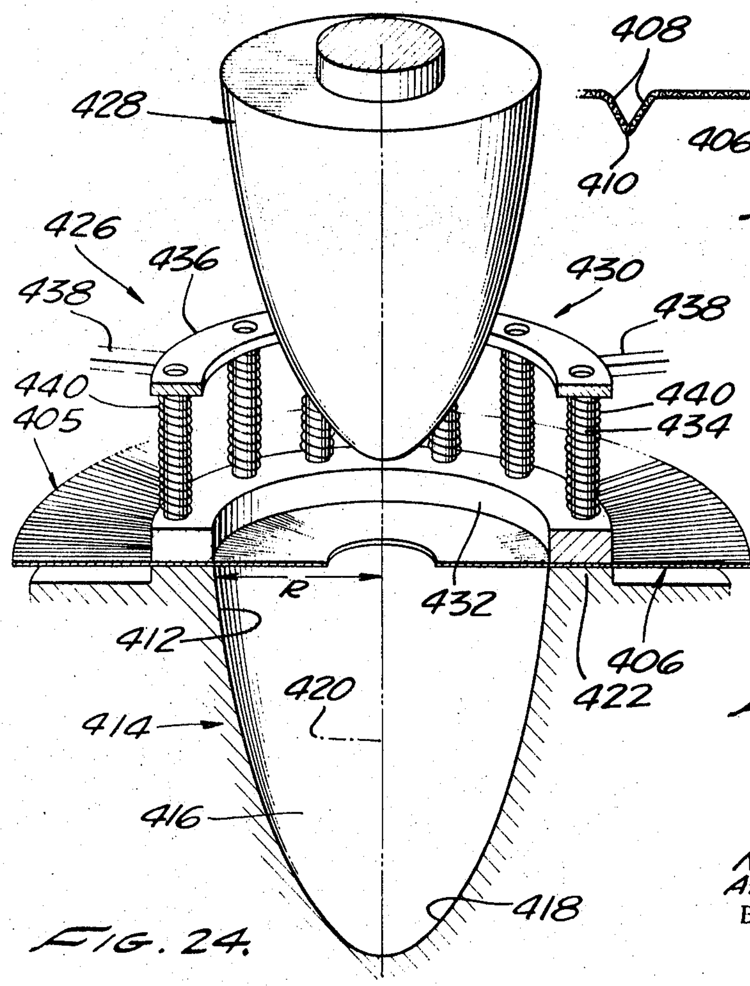

FIG. 24.

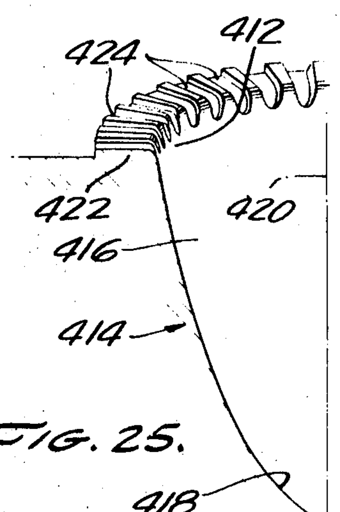

FIG. 25.

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METHOD OF FORMING A SCREEN

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to novel methods of means for cold forming a flat blank into a hollow shell-like concavo-convex shape. The invention relates also to novel hollow liquid-gas separator screens which may be fabricated by the present forming methods and are characterized by an accurately predetermined pore size such that the screens will pass liquids but not gases under normal operating conditions.

As will appear from the ensuing description, the present invention has two basic aspects, one of which is concerned generally with the formation of hollow concavo-convex shapes having compound curvatures and the other of which is concerned with the construction and formation of liquid-gas separators and separator screens. However, the techniques of forming the present separator screens are identical to those involved in forming concavo-convex shapes for other purposes. For this reason, the present disclosure will be devoted primarily to the liquid-gas separator screens and to the techniques of forming the screens.

2. Description of the Prior Art

It is well recognized in the prior art that a fine mesh screen possesses the inherent capability of separating liquids and gases. Screens of this type, for example, have been employed for a variety of liquid gas separation applications, such as removing bubbles of air and other gases from the lubricating oil supplied to jet aircraft engines. The mechanics of the liquid gas separating action which occurs during flow of the liquid through such a screen is well understood and thus need not be explained in detail. Suffice it to say that liquid gas separating screens have a relatively fine mesh defining openings or pores, as they are referred to herein, on the order of 5—200 microns in size and that the liquid gas separating action of these screens involves a surface tension phenomena which permits liquid flow but blocks gas flow through the screen pores because of the strength of the meniscus of the gas bubbles formed over the openings in the mesh as the gas attempts to break down the surface tension of the liquid that is in contact with the screen. If the pressure drop across the screen exceeds the strength of the meniscus the screen will pass gas as well as liquid.

Numerous attempts have been made to form hollow screen liquid-gas separators. None of these attempts have been successful, however, for the reason that the screen forming operation has resulted in relative displacement and/or stretching of the screen strands and resultant enlargement or constriction of the screen pores. This change in pore size, in turn, adversely affects or destroys the liquid gas separating action of the screens.

SUMMARY OF THE INVENTION

One important aspect of this invention is to avoid the problem, just discussed, and thereby enable forming of a liquid-gas separator screen into a hollow concavo-convex shape or shell. According to this aspect of the invention, the intersecting screen strands are preferably (though not necessarily) first joined to one another where they cross, thus to maintain the proper screen pore size during forming, after which the screen is formed to the desired shape by the novel forming techniques explained below. Various screen shapes may be formed using these techniques. Two shapes are disclosed herein by way of illustration, to wit, spherical and ellipsoidal. In this regard, it should be noted that the reason for a spherical shape is that it is used in conjunction with a pressure vessel and the most desirable shape for a pressure vessel with a given volume is a sphere due to the high strength to weight ratio. The vessel is lined with a present spherical screen assembly that is in a close proximity with the inside of the pressure vessel so as to perform a near complete expulsion of the liquid in the vessel before getting a gas breakdown in the annulus between the screen liner and the vessel wall. This permits a bubble free supply of liquid to the outlet port of the vessel with the port in any position. As noted earlier and as will become evident from the ensuing description, the forming techniques of the invention may be employed to produce concavo-convex shells of other shapes, from other materials than screen, and for other uses than liquid gas separation.

As noted earlier, the pore size of a liquid gas separator screen is critical and determines the maximum pressure drop which such a screen can sustain without passing gas. In many applications, the total pressure drop which must be sustained by a liquid-gas separator may exceed, and often greatly exceed, the maximum permissible pressure drop of a single separator screen. According to another of its aspects, the present invention provides a multistage liquid gas screen separator having a number of individual separator screens arranged in series in such a way that flow occurs through the screens successively. In this case, the pressure drop across each screen approximates the total pressure drop across the separator divided by the number of separator screens. Accordingly, a liquid gas separator according to the invention may be designed to accommodate any total pressure drop by providing the separator with the proper number of separator screens.

It is a general object of the invention, then, to provide novel methods of and means for cold forming a flat blank into a hollow shell of concavo-convex shape.

A highly important object of the invention is to provide novel liquid-gas separator screens of concavo-convex shape as well as novel methods of and means for forming the screen.

A further object of the invention is to provide a multistage, screen type liquid-gas separator capable of sustaining a maximum pressure drop without passing gas.

Other objects, advantages, and features of the invention will become readily evident as the description proceeds.

With these and other objects in view, the invention consists of the construction, arrangement, and combination of the various parts of the device, whereby the objects contemplated are attained, as hereinafter set forth, pointed out in the appended claims and illustrated in the accompanying drawings.

In the drawings:

FIG. 1 is a side elevation, partly in section, of a spherical liquid-gas separator according to the invention;

FIG. 2 is an enlarged section taken on line 2–2 of in FIG. 1;

FIG. 3 is an enlarged section taken on line 3–3 in FIG. 1;

FIG. 4 is an enlarged section taken on line 4–4 in FIG. 1;

FIG. 5 is an enlarged fragmentary perspective view of the liquid-gas separator screen embodied in the liquid-gas separator;

FIG. 6 is a fragmentary section through a modified liquid-gas separator according to the invention;

FIG. 7 diagrammatically illustrates a multistage liquid-gas separator according to the invention;

FIG. 8 is a side elevation, partly in section, of an ellipsoidal liquid-gas separator according to the invention;

FIG. 9 is an enlarged section taken on line 9–9 in FIG. 8;

FIG. 10 is an enlarged section taken on line 10–10 in FIG. 8;

FIG. 11 is an enlarged section taken on line 11–11 in FIG. 8;

FIG. 12 is an enlarged section taken on line 12–12 in FIG. 8;

FIG. 13 is an enlarged fragmentary section illustrating a modified liquid-gas separator according to the invention;

FIG. 14 is a perspective view of a screen blank which is employed in one method according to the invention for forming a present hollow concavo-convex separator screen;

FIG. 15 is a perspective view on slightly enlarged scale of a pleated work piece which is produced by pleating the blank of FIG. 14 in accordance with an initial step of the forming method;

FIG. 16 is an enlarged section taken on line 16–16 in FIG. 15;

FIG. 17 is a plan view, on reduced scale, of the pleated work piece after edgewise compression of the work piece in accordance with a subsequent step of the method;

FIG. 18 is an enlarged section taken on line 18–18 in FIG. 17;

FIG. 19 illustrates a subsequent forming step of the method during which the compressed pleated work piece is formed to an arcuate shape;

FIG. 20 is a perspective view illustrating a final step of the method during which the arcuately formed work piece is unfolded in accordion fashion to a hollow concavo-convex shape to form a hollow liquid-gas separator screen according to the invention;

FIG. 21 is a plan view of a screen blank which is employed in an alternative forming method according to the invention for forming a present hollow concavo-convex separator screen;

FIG. 22 is a plan view, on slightly reduced scale, of a pleated work piece which is produced by pleating the blank of FIG. 21 in accordance with an initial step of the alternative forming method;

FIG. 23 is an enlarged section taken on line 23–23 in FIG. 22;

FIG. 24 is a fragmentary perspective view in section of forming apparatus employed in the alternative forming method; and

FIG. 25 is an enlarged fragmentary perspective of a forming die which forms part of the apparatus illustrated in FIG. 24.

Referring first to FIGS. 1 through 5 of these drawings, there is illustrated a hollow liquid-gas separator 10 according to the invention including an inner hollow shell-like separator screen 12 and an outer pressure vessel or tank 14. The inner separator screen 12 and outer tank 14 have similar concavo-convex shapes which, in the present instance, are generally spherical. The screen defines an inner chamber 16. The screen and tank define therebetween an intervening annulus or liquid flow space 18 about the screen. At one end of the separator 10 is an inlet 20 communicating with the screen chamber 16. At the opposite end of the separator is an outlet 22 communicating with the flow space 18. The inner separator screen 12 has a relatively fine mesh and is commonly referred to as micronic screen. As shown best in FIG. 5, the screen is composed of woven intersecting strands 24 which define a multiplicity of rectangular openings 26, or pores as they are referred to herein. These screen pores are sized to effect, by the surface tension phenomena referred to earlier, a liquid gas separating action, whereby the screen permits liquid flow but blocks gas flow through the pores under a pressure drop across the screen less than the critical pressure drop which causes the liquid gas separating action of the screen to break down with resultant passage of gas through the pores. The pores of a typical screen are on the order of 5 to 200 microns in size. As noted earlier, this critical pressure drop is related to and varies with the screen pore size.

As noted earlier, the mechanics of the liquid gas separating action of a liquid gas separating screen is well understood in the art and need not be explained in detail. Suffice it to say that during operation of the liquid-gas separator 10, the liquid and gas to be separated, which may comprise lubricating oil containing entrained bubbles of air or other gas, for example, enter the separator through the inlet 20 and flow into the inner separator chamber 16. Assuming that the pressure drop across the separator is less than the critical pressure drop of the separator screen 12 at which the pressure drop exceeds the strength of the meniscus of gas bubbles formed over the screen pores, the liquid passes through the screen pores 26 into the flow space 18 and then flows through this space to the separator outlet 22. The separator screen 12 blocks the passage, through its pores 26, of the entering gas which thus remains trapped in the chamber 16.

As noted earlier, the spherical separator configuration illustrated in FIGS. 1 through 5, is superior to other shapes from the standpoint of strength to weight ratio for a given storage volume. It has heretofore been impossible to form a hollow screen shape for this purpose owing to the change in the screen pore size which occurred during the forming operation.

One important aspect of the present invention is concerned with forming such a spherical screen shape without distorting the screen of pores. According to this aspect of the invention, the intersecting screen strands 24 of the liquid-gas separator screen 12 are preferably (though not necessarily) joined to one another where they cross, as illustrated at 28, prior to forming of the screen to its hollow concavo-convex shape. This prevents the screen strands from shifting relative to one another and thereby changing the screen pore size during the forming operation. The screen is then formed in the novel way explained below so that the strands are not stretched. Accordingly, the screen pores 26 retain, with a relatively high degree of accuracy, their original size and shape during the forming operation, and the resulting hollow liquid-gas separator screen 12 is capable of effecting an efficient liquid gas separating action.

It will be immediately evident to those skilled in the art that the screen strands 24 may be joined to in various ways, all of which are considered to be within the scope of the invention. One manner in which the strands may be joined, for example, is by a sintering process involving exposure of the separator screen 12, prior to forming, to a sintering temperature and pressure. Alternatively, the strands may be adhesively bonded, braized, welded, or otherwise joined.

While the spherical liquid-gas separator configuration of FIGS. 1 through 5 is superior to other separator configurations from the standpoint of strength to weight ratio, a liquid-gas separator according to the invention may be made in a variety of other geometric shapes. All of these various shapes are considered to be within the scope of the invention.

By way of illustration, reference is made to FIGS. 8 through 12 which illustrate a liquid-gas separator 100 according to the invention having an alternative concavo-convex shape which, in this instance, is ellipsoidal. This modified separator includes an inner separator screen 102 and an outer pressure vessel or tank 104 having similar ellipsoidal shapes. At one end of the separator is an inlet 106 which communicates with the chamber 108 within the screen. At the opposite end of the separator is an outlet 110 which communicates with an annulus or flow space 112 defined between the screen and tank. The inner separator screen 102 is composed of intersecting strands 114 which may be joined to one another where they cross, as shown at 116, and define pores 118 which are sized to permit liquid flow and block gas flow through the pores under a pressure drop across the screen less than its critical pressure drop. The liquid-gas separator 100 functions in precisely the same manner as the earlier spherical separator so that a detailed explanation of the operation of the ellipsoidal separator is unnecessary.

In many applications of the present liquid-gas separators, the total pressure drop which a separator must sustain without breakdown of its liquid gas separating function, and resultant passage of gas through the separator may exceed, and perhaps greatly exceed, the critical pressure drop for a single separator screen. According to another of its important aspects, the present invention provides a unique multistage liquid-gas separator 200 (FIG. 7) for these high pressure drop applications. This multistage separator comprises a number of individual hollow separator screens 202, 204, 206 concentrically arranged one inside of the other, as shown, and an outer tank 208. At one end of the separator is an inlet 210 which communicates with the chamber 212 within the inner screen 202. At the opposite end of the separator is an outlet 214 which communicates with a flow space 216 defined between the outer screen 206 and the tank 208.

During operation of the multistage liquid-gas separator 200, the liquid and gas to be separated enter the separator through its inlet 210 and flow to the inner screen chamber 212. The liquid then flows successively through the separator screens 202, 204, 206 to the outer flow space 216 and then through this space to the separator outlet 214. It is evident that the pressure drop across each separator screen approximates the total pressure drop between the separator inlet 210 and outlet 214 divided by the number of screens. In the illustrated separator, for example, the pressure drop across each separator screen approximates one-third of the total pressure drop across the separator. It is evident, of course, that the surface areas of the separator screens **202, 204, 206** progressively increase and the pressure drops across the screens progressively diminish in the direction of flow through the separator. However, the pressure drop across each screen approximates the total pressure drop divided by the number of screens, as stated above. Accordingly, a liquid-gas separator according to the invention may be designed to accommodate any total pressure drop across the separator by providing the latter with the proper number of separator screens to reduce the pressure drop across each screen below its critical pressure drop. While the illustrated multistage separator has the preferred spherical configuration, a multistage separator according to the invention may, obviously, have any geometric shape, such as the ellipsoidal shape of FIGS. **8** through **12**.

Another important aspect of the invention is concerned with unique methods of and means for forming hollow concavo-convex separator screens of compound curvature for use in the present liquid-gas separators, such as the spherical separator of FIGS. **1** through **5** and the ellipsoidal separator of FIGS. **8** through **12**. As noted earlier, these forming methods may be employed to form hollow concavo-convex shapes or shells having compound curvatures from sheet material other that than screen and for applications other than liquid gas separation but will be described in connection with forming separator screens for the present liquid-gas separators. In the drawings, FIGS. **14** through **20** and FIGS. **21** through **25** illustrate two alternative techniques of forming the present separator screens. For sake of illustration, FIGS. **14** through **20** illustrate the successive steps involved in forming the spherical separator screen **12** of FIGS. **1** through **5** and FIGS. **21** through **25** illustrate the successive steps in forming the ellipsoidal separator screen **102** of FIGS. **8** through **12**. It will become evident from the ensuing description, however, that the forming technique of FIGS. **14** through **20** may be utilized to form an ellipsoidal separator screen and, conversely, the forming technique of FIGS. **21** through **25** may be utilized to form a spherical separator screen. Also, each forming technique may be employed to form other concavo-convex shapes of compound curvature than spherical and ellipsoidal.

According to the present forming method illustrated in FIGS. **14** through **20**, a flat rectangular screen blank **300** whose intersecting strands have been joined in the manner described earlier is folded in successively opposite directions along a series of uniformly spaced fold lines **302** extending parallel to the shorter edges of the blank to form what is referred to herein as a pleated workpiece **304** having a number of contiguous generally V-shaped accordion pleats **306** extending parallel to the latter edges. Each pair of adjacent pleats have a common intervening sidewall **308** and apex edges **310** located at opposite sides of the workpiece.

The next step of the screen forming method involves edgewise compression of the pleated work piece **304** to bring the adjacent pleat sidewalls **308** into face to face contact or abutment, as shown best in FIG. **18**. The resulting workpiece **312** is referred to herein, for convenience, as a compressed work piece.

In the next step of the forming method under consideration, the compressed workpiece **312** is formed to an arcuate shape to provide what is referred to herein as an arcuate workpiece **314** conforming to a plan curve paralleling the planes of the currently abutting pleat sidewalls **308**. This forming operation may be performed in various ways, as by passing the compressed workpiece **312** between forming rolls **316** with the parallel planes of the abutting pleat sidewalls normal to the roll axes in the manner illustrated in FIG. **19**. The curve to which the compressed workpiece is thus formed is determined by the desired geometric shape of the final separator screen. For example, when forming the ellipsoidal screen of FIGS. **21** through **25**, the workpiece is rolled or otherwise formed to an elliptical curvature. FIGS. **14** through **20**, however, illustrate the method of forming the spherical separator screen **12** of FIGS. **1** through **6**. In this case, the compressed workpiece **312** is rolled or otherwise formed to a circular arc having a radius equal to the radius of the finished spherical separator screen.

After forming, the arcuate workpiece **314** is unfolded along a circular direction line **318**, as shown in FIG. **20**, to bring the outer walls **308** of the two outer pleats **306** into contact. These walls are then welded or otherwise joined at **320** (FIG. **4**) to provide the spherical separator screen **12**.

It is obvious that in this method of forming a hollow concavo-convex separator screen, the adjacent pleat sidewalls **308** of the finished separator screen will have a maximum circumferential spacing midway between the ends of the pleats and will converge in the directions of these ends. At their ends, the adjacent pleat sidewalls will be disposed in close proximity or will abut one another. The combined overall thickness of the several abutting pleats at each end of the screen defines a minimum circular circumference to which the ends of the arcuate work piece **314** may for conform in the unfolded condition of FIG. **20**. Obviously, this limitation requires that the dimension of the original screen blank **300**, measured between its longer sides and hence lengthwise of the pleats **306** which are formed in the blank, be somewhat less than one-half the circumference of the pleated spherical screen **12**, such that the ends of the pleats of the screen will conform to circles having a circumference equal to or greater than the combined overall compressed width of the pleat ends. Accordingly, the finished spherical separator screen **12** will have generally circular openings **322** at its ends. The same reasoning applies, and the same result will obtain, of course, when forming other concavo-convex screen shapes by this method, such as an ellipsoidal screen.

According to the present invention, the end openings **322** are sealed by circular plates **324** and **326** which are welded or otherwise joined to the adjacent ends of the screen, as shown. The separator inlet **20** comprises a tube which extends coaxially through and is joined to the end plate **324**. This tube continues coaxially through the separator screen **12** and is joined at its distal end to the center of the opposite end plate **326**. The inlet tube has ports **328** opening to the interior chamber **16** of the screen and extends through and is welded at its outer end to the tank **14**. The separator outlet **22** comprises a tube which extends through the tank opposite and on the axis of the end plate **326** and is welded to the tank and plate.

The internal diameter of the tank **14** approximates the outer diameter of the separator screen **12**, measured between the outer apex edges **310** of diametrically opposite pleats **306**. Accordingly, when the screen is placed in the tank, the screen pleats engage the inner surface of the tank. Thus, in addition to the function which the pleats serve in connection with forming the separator screen **12**, the pleats also serve to support and center the screen in the tank **14** and to define with the tank a number of channels or passages **330** between adjacent pleats. These passages together form the flow space **18** referred to earlier.

As noted earlier, the circumferential spacing between the adjacent screen pleats **306** is greatest midway between and progressively diminishes towards the ends of the pleats. At these ends, the pleat sidewalls **308** are in close proximity or in contact. As a consequence, the flow passages **330** defined between the adjacent pleats are constricted at the ends of the pleats so that clearance must be provided between the apex edges **310** of the pleats and the surrounding tank **14**, at the ends of the pleats to permit liquid flow from the passages to the tank outlet **22**. In the drawings, this is accomplished by bulging the tank wall outwardly about the outlet, as shown, to communicate the outlet with the adjacent ends of the passages **330**.

It will now be evident that other shapes may be formed by the present method. For example, the compressed pleated work piece of FIG. **18** may be opened or unfolded normal to the pleats into the form of a cylinder or sleeve. Alternatively, the rolling step of FIG. **19** may be continued until the pleated compressed work piece is formed into a ring, after which the work piece may be opened or unfolded normal to the pleats into the form of a torus. Further, the roller compressed work piece of FIG. **19** may be opened or unfolded in such a way that the concave surface of the work piece is outermost, thus to form a generally hourglass shape.

Reference is now made to FIGS. **21** through **25** which illustrate an alternative method of forming a liquid-gas separator screen according to the invention. This forming method is illustrated in connection with forming an ellipsoidal separator screen **102** of the kind shown in FIGS. **8** through **12**. It will become readily evident as the description proceeds, however, that the same method may be employed to form separator screens of other shapes, such as the spherical screen of FIGS. **1** through **5**.

The screen forming method illustrated in FIGS. **21** through **25** involves the use of a circular screen blank **400** whose intersecting strands may have been previously joined to one another in the manner explained earlier. According to the present invention, the blank **400** is folded along uniformly spaced groups **402** of three uniformly spaced radial fold lines **404** to form a pleated workpiece **405** having a number of similar, uniformly spaced radial pleats **406** with sidewalls **408** joined along meeting apex edges **410**. In contrast to the earlier screen forming method of the invention, the adjacent pleats **406** are not contiguous and do not have common sidewalls. The spacing between and the height of the pleats **406** will be explained presently. For reasons which will appear as the description proceeds, the fold lines **404**, and hence the pleats **406**, do not extend the full radial distance of the pleated work piece **405**. In actual practice, for example, the radial length of the pleats is on the order of 70 percent of the original blank radius. The pleats extend to the outside edge of the workpiece, as shown.

According to the next step of the screen forming method, the pleated workpiece **405** is coaxially placed over the open side **412** of a hollow forming die **414** having a forming cavity **416**, with the pleats **406** of the workpiece facing the die, as shown. The die cavity **416** conforms to the desired shape of the finished separator screen. In the drawings, for example, the die cavity **416** is ellipsoidal in shape and is bounded by a wall **418** which conforms to a surface of revolution generated by rotation, about the forming die axis **420**, of an elliptical curve having one end situated on the axis and its opposite end radially spaced from the axis a distance R equal to the radius of the finished ellipsoidal screen measured in a plane normal to the axis of and intersecting the screen midway between its ends. The spacing R, of course, is the radius of the forming die opening **412** and is somewhat less than the radius of the original screen blank **400**. The open side of the forming die cavity **416** is surrounded by a raised serrated rim **422** having a number of uniformly spaced radial grooves **424** opening through its upper face. The pleated workpiece **405** is placed over the open side **412** of the forming die **414** in such a way that the pleated side of the blank rests on the rim **422** with the pleats **406** of the blank engaging in the rim grooves **424**. To this end, the grooves and pleats are equal in number. For reasons which will appear presently, the circumferential width of each rim groove **424** is substantially greater than the outer width of each pleat **406**.

The forming die **414** comprises one element of forming apparatus **426** which is employed in the practice of the present screen forming method. This forming apparatus includes, in addition to the forming die, a forming mandrel **428** for deforming the pleated workpiece **405** into the die cavity **416**, in the manner explained below, and a clamping structure **430** which cooperates with the serrated rim **422** of the forming die to frictionally grip the pleated work piece about the forming cavity. This clamping structure includes a clamping ring **432** which is located directly over and has about the same radial dimensions as the forming die rim **422**. Secured at their lower ends to and rising from the clamping ring **432** are a number of uniformly spaced posts **434**. The upper ends of these posts extend slidably through bores in and are thereby slidably guided by an upper supporting ring **436** located over and in a plane parallel to the forming die rim **422**. This supporting ring is mounted in a fixed position in any suitable way. In the drawings, for example, the supporting ring is provided with a number of rigid, radially extending supporting struts **438** which are firmly attached to a suitable supporting structure (not shown). Surrounding the clamp ring posts **434** are springs **440** which yieldably urge the clamping ring **432** toward the rim **422** of the forming die **414**. The pleated workpiece **405** when in its initial forming position across the open side **412** of the forming die **414**, is located and frictionally gripped between the forming die rim **422** and the clamping ring **432**.

The shape of the forming mandrel **428** conforms to the shape of the forming die cavity **416**. Thus, in the drawings, the forming mandrel has an ellipsoidal shape like that of the forming cavity. The dimensions of the forming mandrel, however, are less than the corresponding dimensions of the forming cavity by an amount which approximates the pleat height of the pleated workpiece **405**. The forming die and forming mandrel are coaxially supported by suitable supporting means (not shown) for relative movement toward and away from one another along their common axis **420**. Suitable means, such as a hydraulic ram (not shown) are provided for driving the forming die and mandrel in their relative axial movement. In this description, it is assumed that the forming die **414** is stationarily mounted and that the forming mandrel **428** is driven axially relative to the die between its retracted position of FIG. **24**, wherein the mandrel is retracted from the forming die cavity **416**, and an extended position, wherein the mandrel is concentrically disposed within the cavity.

According to the next step of the screen forming method under discussion, the forming mandrel **428** is driven downwardly toward and finally into the forming die cavity **416** to draw the pleated workpiece **405** into the cavity, thus to form a screen shell having an ellipsoidal shape conforming to the shape of the cavity. During this forming operation, the pleated workpiece is drawn radially inward between the confronting clamping surfaces of the forming die rim **422** and the clamping ring **432** and then downwardly into the forming cavity **416**. The clamping ring **432** frictionally grips the pleated workpiece as the latter is drawn into the forming cavity and serves to prevent undesirable bulging or buckling of the screen as the latter enters the cavity. The grooves **424** in the forming die rim **422** provide clearance for the pleats **406** of the workpiece. In this regard, it is evident that the circumferential spacing between adjacent pleats increases toward the outer perimeter of the pleated workpiece. Accordingly, the width of the rim grooves must be sufficient to accommodate this increase in the circumferential spacing between the pleats as the pleated workpiece is drawn inwardly between the forming die rim **422** and the clamping ring **432**.

It is evident that as the pleated workpiece **405** is drawn into the forming cavity **416**, the circumferential dimension of the workpiece, at any given radial distance from the center of the workpiece, progressively diminishes by an amount which is inversely proportional to the radial distance. Thus, the outer circumference of the blank diminishes the most and, in the finally formed ellipsoidal shell or screen produced by the method, this outer circumferential dimension approximately equals the circumference of the open side **412** of the forming die cavity **416**. According to the present invention, the reduction in the circumferential dimensions of the pleated workpiece which occurs during forming of the workpiece in the die cavity is accommodated by the pleats **406**. Thus, as the pleated workpiece **405** is drawn into the cavity, the pleats effectively gather, that is the sidewalls **408** of each pleat deflect toward one another, to permit circumferential shrinking of the workpiece as the latter enters the forming cavity. Since the reduction in the circumferential dimension of the workpiece progressively diminishes toward the center of the workpiece and becomes minimal adjacent the center, it has been found that the pleats need not extend completely to the center of the workpiece. It has been discovered, for example, that an ellipsoidal screen according to the invention may be satisfactorily formed, in the manner described above, with a radial pleat length which is on the order of 70 percent of the radius of the original screen blank 400. Preferably, the original blank 400 is formed with a central opening 442 to avoid undesirable distortion or deformation of the screen at the center of the pleated workpiece during forming. It is obvious that the outer circumference of the pleated workpiece 405, when the pleats 406 are fully compressed, i.e., their sidewalls 408 abut one another, represents the minimum outer circumference to which the workpiece may be formed in the die cavity 416 without undesirable buckling or other undesirable deformation of the workpiece in the regions between the pleats. This minimum circumferential dimension of the pleated workpiece, in turn, determines the minimum circumferential dimension and hence radius of the open side 412 of the forming cavity 416 as well as the major diameter of the finally formed screen shell.

Analyzing the present forming method from another point of view, it is evident from the description thus far that the pleated workpiece 405 has a maximum outer circumference and radius when the pleats 406 are flattened. In this flattened condition of the pleats, of course, the pleated workpiece has the same circumferential and radial dimensions as the flat original blank 400. Assume now that the pleats are gathered or compressed to their limiting mode, wherein the sidewalls 408 of each pleat abut one another. When the pleats are thus gathered or compressed, the outer circumference or circumferential edge of the pleated workpiece progressively shrinks to its minimum circumference, mentioned above, and the workpiece assumes the shape of a hollow shell having an open side bounded by the outer circumference, or outer circumferential edge, of the workpiece. The outer circumference of this gathered workpiece has a radius, measured in a plane containing the outer circumference or circumferential edge, which progressively diminishes to a minimum radius as the circumference diminishes or shrinks as a result of gathering of the pleats. This minimum radius pr represents the minimum radius to which the outer circumference of the pleated workpiece may be formed in the die cavity 416 without buckling of the workpiece in the regions between the pleats and hence the minimum radius of the open side 412 of the forming cavity 416. The above-mentioned maximum and minimum radii of the pleated workpiece 405 define a radii range within which the radius of the open side of the die cavity must fall to enable forming of the present separator screen without buckling. It is evident, of course, that the difference between the maximum and minimum radii and hence the radii range, may be varied by increasing the number and/or height of the pleats 406. Thus, increasing the number and/or height of the pleats effectively increases the radii range and thus permits forming of the pleated workpiece to a smaller minimum radius in the forming cavity 416. In actual practice, the open side 412 of the forming cavity 416 will have a radius slightly greater than the minimum radius to which the outer circumference of the pleated workpiece 405 may be formed without buckling, so that the pleats 406 in the finally formed workpiece, or separator screen, will not be fully gathered or compressed, but rather will have a V-shape in transverse cross section, as shown.

The forming method described above produces a hollow screen shape which constitutes one-half or one end of the completed ellipsoidal liquid-gas separator screen 102, illustrated in FIGS. 8 through 12. A complete separator screen 102 is produced by forming a pair of hollow ellipsoidal screen shapes or shells in the manner discussed above and joining these shells end to end with their open sides facing one another. The two shells may be joined in various ways. In FIGS. 8 through 12, for example, the shells are welded to an intervening ring 444, as shown. The openings 442 in the ends of the separator screen are closed by end plats plates 446, 448 to which the screen is welded, in the same way as described earlier in connection with the spherical separator screen of FIGS. 1 through 5. The separator screen inlet 106 and outlet 110 comprise tubes which are welded to these end plates and extend to the outside of the separator tank 104, also in the same way as described earlier in connection with the spherical separator and illustrated in FIGS. 8 through 12. Referring to these latter figures, it will be observed that the pleats 406 of the separator screen 102 engage the wall of the surrounding tank 104 to support and center the screen in the tank. The tank and adjacent pleats define channels 450 which extend lengthwise of the separator screen and together constitute the flow space 112 through which liquid passing through the screen pores 118 flows to the tank outlet 110. As in the earlier form of the invention, the tank wall is bulged outwardly about the outlet to communicate the latter to the flow channels 450.

In some cases, it may be desirable or necessary to provide a flow space between the screen and tank of a present liquid-gas separator by means other than pleats in the screen. This may be accomplished in various ways. In FIGS. 6 and 13, for example which are enlarged sections through spherical and ellipsoidal separators according to the invention, the separator screens 12*a* and 102*a*, respectively, are spaced from their surrounding tanks 14*a* and 104*a* by intervening wire cages 452. These wire cages provide flow spaces 454 about the screens through which the liquid emerging from the screen pores may flow to the separator outlet (not shown).

While the invention has herein been shown and described in what is conceived to be the most practical and preferred embodiment, it is recognized that departures may be made therefrom within the scope of the invention, which is to be accorded the full scope of the claims so as to embrace any and all equivalent devices.

We claim:

1. The method of fabricating a hollow liquid-gas separator from a fine mesh screen blank composed of woven intersecting strands defining a multiplicity of relatively small rectangular pores which are sized to permit liquid flow and block gas flow through the pores under a pressure drop across the screen less than a critical pressure drop related to the pore size, said method comprising the steps of:

mutually joining the intersecting strands of said screen blank where they cross one another, and

thereafter forming said screen blank to an oblate spheroidal shape without stretching of said strands, thereby to maintain substantially the original size and shape of said pores.

2. The method according to claim 1 wherein said joining step involves exposing said screen blank to a sintering temperature and pressure.

3. The method of forming a hollow oblate spheroidal shell from a flat rectangular blank of flexible sheet material, said method comprising steps of:

folding said blank in successively opposite directions along generally uniformly spaced fold lines extending parallel to two parallel edges of said blank to form a pleated workpiece with contiguous generally V-shaped accordion pleats in such manner that each pair of adjacent pleats have a common intervening wall and apex edges located at opposite sides of said workpiece,

compressing the pleated workpiece edgewise in a direction normal to said fold lines to bring the adjacent pleat sidewalls into face-to-face contact and thereby provide a compressed workpiece wherein said pleat sidewalls are disposed in substantially parallel planes,

forming said compressed workpiece to an arcuate shape to provide an arcuate workpiece conforming to a plane curve paralleling said sidewalls planes, and

unfolding portions of said curved workpiece intermediate the ends along a generally circular direction line normal to said fold lines to bring the outer sidewalls of the outer pleats into contact while holding opposite ends to prevent unfolding to the same extent as the portions intermediate the ends.

4. The forming method according to claim 3 including the additional step of joining said outer sidewalls to one another.

5. The forming method according to claim 3 wherein:

said blank comprises a fine mesh screen composed of woven intersecting strands defining a multiplicity of relatively small rectangular pores which are sized to permit liquid flow and block gas flow to said pores under a pressure drop across said screen less than a critical pressure drop related to the pore size, and

said method comprises the additional step of joining said outer pleat sidewalls to form a hollow liquid-gas separator screen.

6. The forming method according to claim 5 wherein:

said blank is dimensioned lengthwise of said pleats to define generally circular openings at the ends of said separator screen, and

the circumferential dimension of each said opening being at least equal to the edgewise width of said compressed workpiece measured normal to said fold lines.

7. The method of forming a hollow concavo-convex shell from a circular blank of flexible material which comprises the steps of:

folding said blank along generally uniformly spaced groups of three generally uniformly spaced radial fold lines extending from the outer edges of said blank to a position adjacent the center of said blank to form a pleated workpiece with generally uniformly spaced, radially extending accordion pleats which project beyond one side of said workpiece, and

forming said pleated workpiece by deforming its central portion relative to its outer perimeter in a direction normal to its plane and into a concavo-convex shape conforming approximately to a surface of revolution generated by rotating about an axis normal to and passing through the center of said pleated workpiece a plane curve having one end situated on said axis and its other end spaced from said axis a radial distance less than the radius of said blank.

8. The forming method according to claim 7 wherein:

the perimeter of said pleated workpiece has a minimum radius less than said given radius when said pleats are compressed to bring the sidewalls thereof into face to face contact,

said given and minimum radii define the limits of a radii range, and

said radial distance is within said range and less than said given radius.

9. The forming method according to claim 8 wherein:

said blank comprises a fine mesh screen composed of woven intersecting strands defining a multiplicity of relatively small rectangular pores which are sized to permit liquid flow and block gas flow under a pressure drop across said screen less than a critical pressure drop related to the pore size, and

said screen when finally formed has a open side and is adapted to be joined about said open side with a similar screen to form a liquid-gas separator.

10. The forming method according to claim 7 wherein said forming step involves placing said pleated workpiece across the open side of the forming die having a forming cavity with a wall conforming to said surface of revolution, frictionally gripping said pleated workpiece in the regions between said pleats, and deforming said pleated workpiece into said cavity.