Dec. 27, 1966 P. J. THRASH 3,294,108

GAS LIFT VALVE

Filed Jan. 20, 1964 2 Sheets-Sheet 1

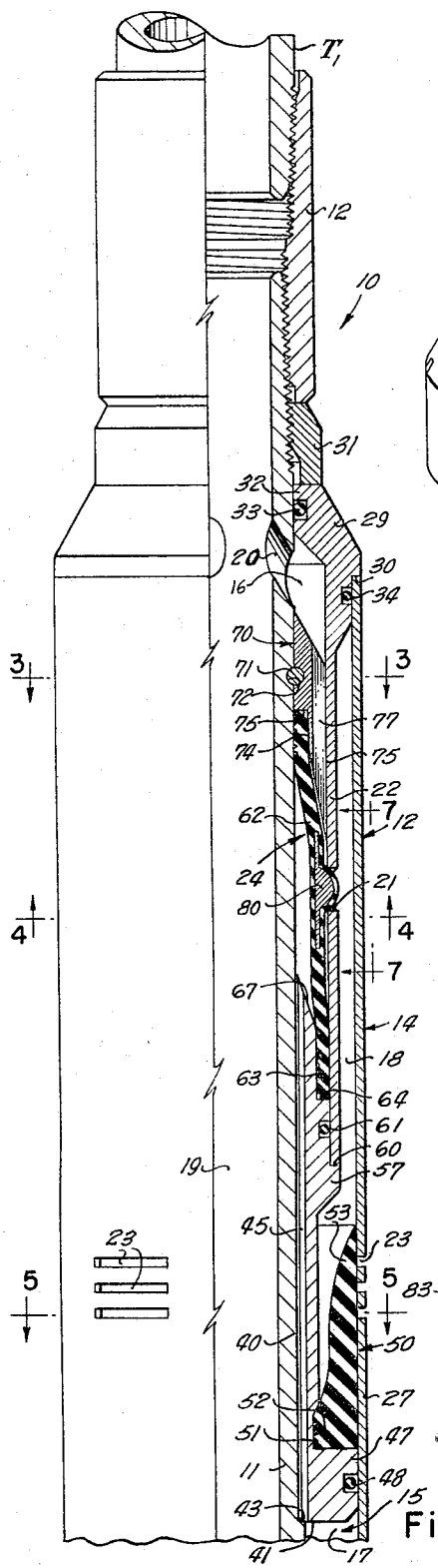


Fig. 1

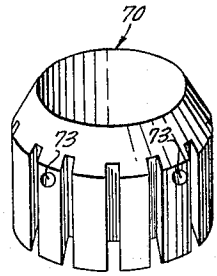


Fig. 6

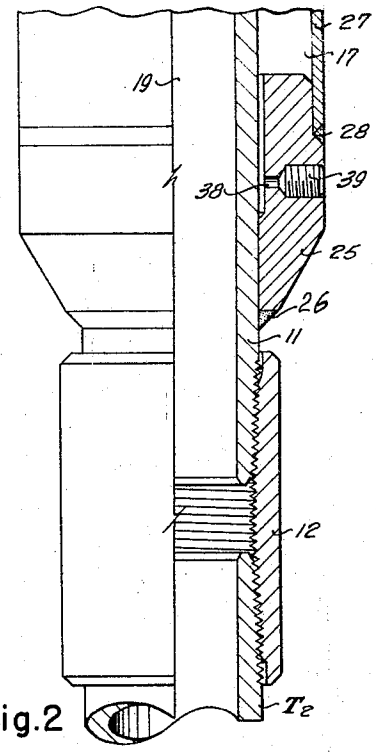


Fig. 2

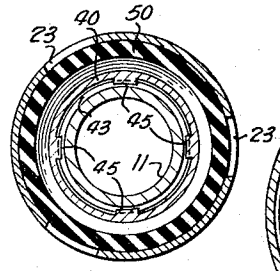


Fig. 5

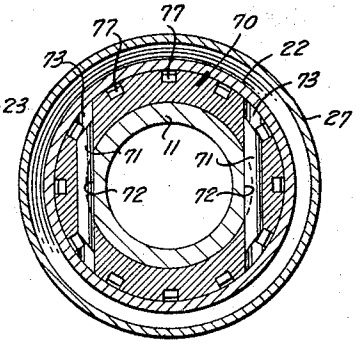


Fig. 3

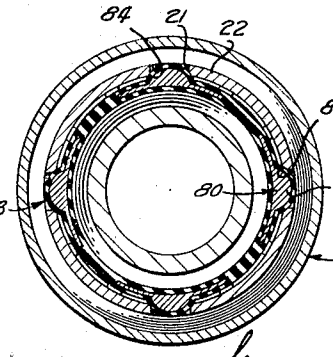


Fig. 4

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Dec. 27, 1966 P. J. THRASH 3,294,108

GAS LIFT VALVE

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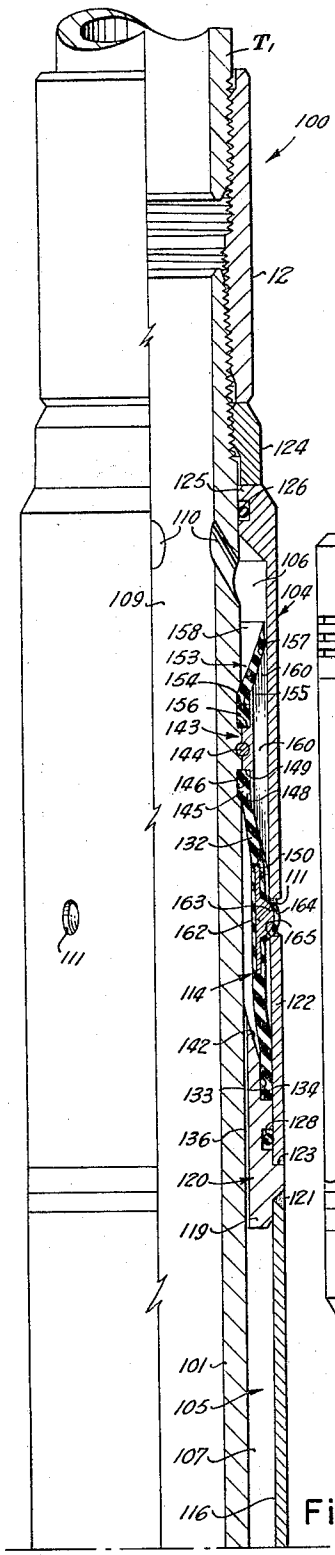


Fig. 8

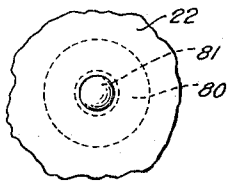


Fig. 7

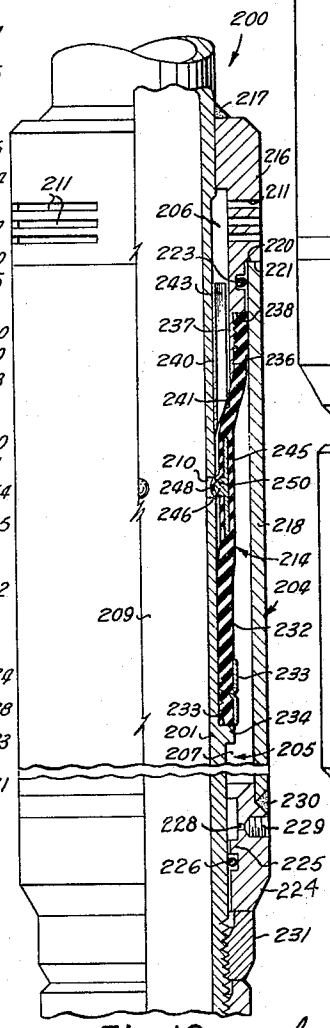


Fig. 10

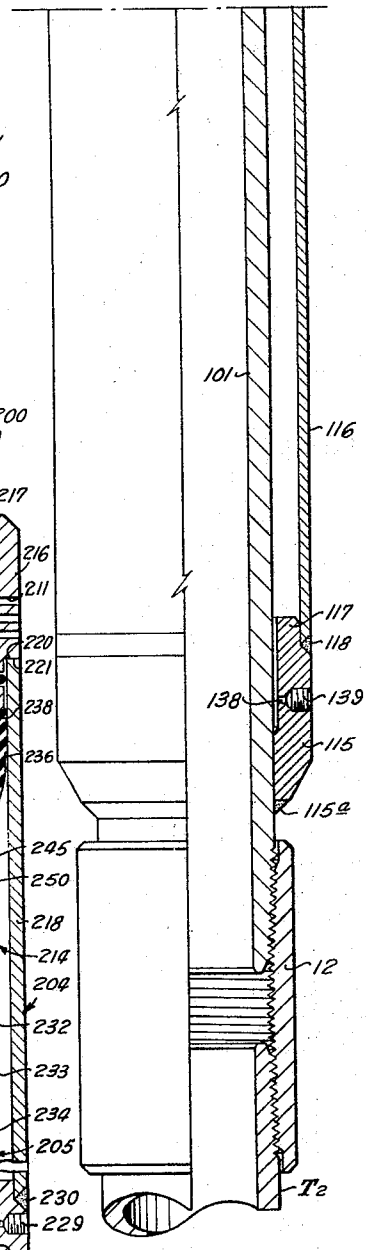


Fig. 9

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GAS LIFT VALVE

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Filed Jan. 20, 1964, Ser. No. 338,845
7 Claims. (Cl. 137—155)

This invention relates to well tools and more particularly to air or gas lift valves for use in oil wells and the like for controlling admission of gas or air to a column of fluid in the well to lift the column and aid in flowing the fluid from the well.

In conventional gas lift systems, the well equipment usually includes a string of relatively small pipe called a tubing which is inserted inside a larger diameter pipe called the casing. The liquid produced by the well flows to the surface through the tubing and air or gas is introduced under controlled pressures and volumes into the annular space or annulus between the tubing and the casing and injected by suitable gas lift valves into the tubing to aid in lifting the column of well fluids or oil inside the tubing to the surface.

It is desirable that such gas lift valves be of such structure that the bore of the tubing is not decreased at the location where the gas lift valves are connected to the tubing in order to permit the passage of well tools through such gas lift valves and that, additionally, the external diameter of such valves be as small as possible in order to permit passage of tools through the annulus during "washover" operations of the well and the like. It is further desirable in some wells that the operation of the gas lift valves be responsive only to the fluid pressure in the tubing at the location of the gas lift valve.

Accordingly, an object of this invention is to provide a new and improved gas lift valve connectable in a string of tubing to form a section thereof and having a central longitudinally passage or bore of a diameter not smaller than the bore of the tubing.

Another object is to provide a gas lift valve of concentric construction connectable in a string of tubing to constitute a section thereof and having an internal longitudinal passage whose diameter is not smaller than the internal diameter of the tubing and an annular flow passage disposed concentrically above the longitudinal passage, the valve having ports communicating the annular flow passage with the longitudinal passage and ports communicating the annular flow passage with the exterior of the valve, and a valve means disposed in the flow passage and biased towards closed position wherein it closes the ports communicating the annular flow passage with the exterior of the valve, the valve means having a large area on which the fluid pressure from within the longitudinal passage exerts a force tending to move the valve means toward open position and having a small area on which the fluid pressure from the exterior of the valve exerts a force tending to move the valve means toward open position whereby operation of the valve is responsive primarily to the pressure from within the longitudinal passage.

Still another object is to provide a gas lift valve wherein the valve means is in the form of a tubular sleeve having a plurality of circumferentially spaced external spherical protuberances for closing the ports of the valve through which fluid from the exterior of the valve flows to the annular flow passage.

A further object is to provide a gas lift valve wherein the tubular sleeve valve is provided with a plurality of reinforcing inserts having spherical protuberances which engage annular seat surfaces of the valve and having lateral projecting substantially rigid portions surrounding said protuberances which hold the external surface of the

sleeve valve spaced from internal surfaces of the valve provided with the ports whereby large areas of the sleeve valve and the valve inserts are subjected to the force of the fluid pressure from the longitudinal passage tending to move the sleeve valve to its contracted or open position and only small areas of the protuberances and rigid inserts are subjected to the force of the fluid pressure from the exterior of the valve tending to move the protuberances inwardly and therefore the sleeve valve to open position.

A still further object is to provide a valve having a tubular mandrel and a housing disposed on the mandrel providing an annular longitudinal space about the mandrel divided intermediate its ends into a charge chamber and an annular flow passage by a tubular flexible sleeve valve, the sleeve valve being biased outwardly toward expanded position closing ports of the housing communicating the annular flow passage with the exterior of the valve, the mandrel also having parts communicating the annular flow passage with the interior of the mandrel, the sleeve valve having means for causing a relatively large area of the sleeve valve to be subjected to forces exerted thereon by the fluid pressure from the interior of the mandrel tending to move the sleeve valve to its open position and only a small area thereof subjected to forces exerted by fluid pressure from the exterior of the valve.

Still another object is to provide a new and improved sleeve valve having a tubular resilient body and a plurality of circumferentially spaced rigid inserts embedded in said sleeve and body, the inserts having spherical external protuberances whereby the sleeve valve is provided with circumferentially spaced protuberances for engaging annular seat surfaces surrounding ports of a tubular member in which the sleeve is positionable.

Still another object is to provide valve having a tubular mandrel and a housing disposed on the mandrel providing an annular longitudinal space about the mandrel divided intermediate its ends by a tubular flexible sleeve valve into a charge chamber and an annular flow passage, the mandrel having ports opening between one end of the annular flow passage and the interior thereof and the housing having ports opening from the exterior thereof into the other end of said annular flow passage, the sleeve valve having means engageable with one of the tubular mandrel and the housing for closing the ports thereof and preventing flow from the exterior of the housing through the annular flow passage into the mandrel.

Still another object is to provide a gas lift valve wherein the annular sleeve valve is provided with radially extending protuberances engageable with seat surfaces about the ports of one of the mandrel and the housing for closing the ports when the pressure within the tubing and mandrel exteriorly of the valve exceed predetermined different values whereby the sleeve valve will move to its open position when the pressure exteriorly of the housing exceeds the value of the fluid pressure in the charge chamber in the valve and the pressure within the mandrel exceeds a second value which is lower than the value of the fluid pressure exteriorly of the valve whereby fluid will flow from the exterior of the valve through the annular flow passage and into the mandrel.

Additional objects and advantages of the invention will be readily apparent from the reading of the following description of a device constructed in accordance with the invention, and reference to the accompanying drawings thereof, wherein:

FIGURE 1 is a vertical, partly sectional view of the upper portion of a gas lift valve embodying the invention showing it connected to a string of tubing;

FIGURE 2 is a view similar to FIGURE 1 showing the lower portions of the gas lift valve;

FIGURE 3 is a sectional view taken on line 3—3 of FIGURE 1;

FIGURE 4 is a sectional view taken on line 4—4 of FIGURE 1;

FIGURE 5 is a sectional view taken on line 5—5 of FIGURE 1;

FIGURE 6 is a perspective view of a retainer member of the valve;

FIGURE 7 is a fragmentary side view taken on line 7—7 of FIGURE 1;

FIGURE 8 is a vertical, partly sectional view of the upper portion of a modified form of the valve embodying the invention;

FIGURE 9 is a view similar to FIGURE 7 showing the lower portion of the valve; and,

FIGRE 10 is a fragmentary vertical partly sectional view of another modified form of the valve embodying the invention.

Referring now particularly to FIGURES 1 through 7 of the drawings, the gas lift valve **10** includes a tubular mandrel **11** externally threaded at its opposite ends whereby it is connectable to upper and lower tubing sections T1 and T2 of a string of tubing to constitute a section of the string of tubing by means of the usual coupling collars **12**. A tubular housing **14** is disposed on the mandrel intermediate its ends and provides a longitudinally extending space or chamber **15** about the mandrel **11** which is divided into an annular inner flow passage **16**, an annular charge chamber **17** and an outer annular passage **18**. The upper end of the inner annular flow passage **16** is in communication with the longitudinal flow passage **19** of the mandrel by means of a plurality ports **20** thereof. The lower end of the inner flow passage communicates with the exterior of the valve through a plurality of ports **21** of an inner sleeve **22** of the housing, the outer flow passage **18** and the lateral ports or slots **23** of the housing. The effective total orifice of the ports **21** is substantially smaller than the effective total orifice of the lateral ports **20** in order that a pressure differential may be created between the inner passage and the outer passage for a purpose to be described below.

Flow of fluid from the outer annular passage into the inner annular passage is controlled by a sleeve valve **24** biased radially outwardly toward expanded or closed position closing the ports **21** by a charge of compressed gas in the charge chamber **17**.

The housing **14** includes an annular bottom section **25** rigidly secured to the mandrel, as by a weld **26**, an intermediate port section **27** whose lower end is telescoped over the upper reduced portion of the housing bottom section and is rigidly secured thereto, as by the weld **28**, and a top section **29** which has the dependent annular inner sleeve **22**. The top section **29** is telescoped into the upper end of the port section **27** and its downward movement thereinto is limited by the engagement of its annular downwardly facing stop shoulder **30** with the top end surface of the port section. A retainer ring **31** threaded on the upper end of the mandrel engages the top housing section to limit its upward movement relative to the mandrel and to the port housing section. The top housing section has an internal annular flange **32** provided with an internal annular recess which is disposed an O-ring **33** which seals between the top housing section and the mandrel above the mandrel ports **20**. The top housing section also has an external recess in which is disposed an O-ring **34** which seals between the top and port housing sections. The bottom housing section has an inlet port **38** through which gas under pressure may be introduced into the charge chamber **17** and which is closable by a suitable plug **39** threaded in the outer enlarged portion of the inlet port.

A lower annular valve retainer **40** is disposed about the mandrel and is held against downward movement thereon by the engagement of its bottom annular end surface **41** with the upwardly facing external annular shoulder **43** of the mandrel provided by the enlargement of its lower portion. The lower valve retainer has one or more internal longitudinal grooves **45** which permit communication of fluid pressure from below the valve retainer to the internal surfaces of the sleeve valve **24**.

The lower valve retainer has an external annular flange **47** provided with an external annular recess in which is disposed an O-ring **48** which seals between the flange and the port housing section below the ports **23** thereof.

An annular resilient check valve **50** has an annular internal flange **51** disposed in an annular external groove **52** of the lower valve retainer located above its flange **47**. The external annular surfaces of the check valve engage the internal surfaces of the port housing section about the ports **23** thereof to prevent fluid flow from the outer annular passage **18** to the exterior of the housing through the ports **23**, whenever the pressure within the outer annular passage **18** exceeds the pressure exteriorly of the housing. The upper lip portion **53** of the check valve flexes resiliently inwardly to permit fluid flow inwardly through the ports **23** into the outer flow passage **18**.

The lower valve retainer is enlarged above the check valve, as at **57**, to provide an upwardly facing annular shoulder **60** which engages the bottom annular end surface of the inner sleeve **22** to limit its downward telescoping movement over the upper portion of the lower valve retainer. An O-ring **61** is disposed in an external annular recess of the lower valve retainer and seals between the valve retainer and the inner sleeve **23**.

The lower end portion of the resilient tubular body **62** of the sleeve valve **24** extends between and engages the internal surface of the port housing section and the external annular surface **63** of the lower valve retainer above its annular upwardly facing shoulder **64**. The lower end portion of the body of the valve sleeve is compressed between the surfaces of the port housing section and the lower retainer and seals therebetween.

The annular top end surface **67** of the lower valve retainer is tapered upwardly and inwardly to permit and control inward flexing movement of the body of the valve sleeve and to support it when it is flexed inwardly.

The upper valve retainer **70** is disposed in the inner annular flow passage **16** between the ports **20** and **21** and is secured to the mandrel by a pair of pins **71** whose inner portions are received in tangential grooves **72** of the mandrel and which are held in the parallel transverse bores **73** of the upper valve retainer. Intermediate portions of the bores **73** open inwardly and are aligned with the tangential grooves of the mandrel.

The upper end portion of the body **62** of the sleeve valve extends between and engages the external surface of the mandrel and the internal annular surface **74** of the upper valve retainer below its annular downwardly facing shoulder **75** and is held in compressed sealing engagement between the retainer surface **74** and the external surface of the mandrel below its ports **20**. The lower end surface **75** of the upper valve retainer is curved arcuately downwardly and outwardly to support the body of the sleeve valve in the event it is expanded outwardly beyond the normal expanded position illustrated in FIGURE 1. The upper retainer has a plurality of longitudinal circumferentially spaced grooves or slots **77** which permit fluid flow past the upper valve retainer.

The body **62** of the sleeve is fomed of a resilient substance, such as neoprene, and has a plurality of circumferentially spaced rigid reinforcing inserts **80** molded or embedded therein so that the inserts are completely covered by the resilient substance of which the body is formed. Each of the rigid inserts is substantially circular in form and has a central external semi-spherical boss **81**. The bosses **81** of the rigid inserts cause the sleeve valve to have a plurality of substantially semi-spherical external protuberances **83** which extend outwardly into the ports **21** of the sleeve **22** and which engage the annular seats **84** of the sleeve **22** which extend above the ports. The

resilient substance of body which covers the protuberances **81** of the inserts provides a resilient seal between the protuberances and the seats **84**. The protuberances **83** are of such radius that the outer surface of the body of the valve sleeve is held spaced inwardly of the internal surfaces of the sleeve **22** when the valve is in its fully expanded closed position in order that fluid pressure from the longitudinal passage **19** of the mandrel, and therefore from the tubing, is transmitted through the ports **20** and the inner annular passage **16** to the external surface of the valve sleeve and exerts an inwards force on all surfaces of the inserts which extend outwardly of the line of sealing engagement of the protuberances **83** with the annular seats **84**. The inserts extend upwardly of the lowermost end portions of the upper valve retainer so that when the sleeve valve is in its fully expanded position the lower ends of the longitudinal slots **77** are not closed but open into the annular space between the inner sleeve and the sleeve valve. The area of the rigid inserts disposed outwardly of the line of sealing engagement of the protuberances and the seats **84** is considerably greater than the area thereof disposed inwardly of such line of sealing engagement as is evident in FIGURES 1, 4 and 7.

In use, the charge chamber **17** is charged with a compressible fluid through the inlet port **38** of the housing to a predetermined pressure and the inlet port is then closed by a plug **39**. The pressure of the fluid in the charge chamber is communicated to the internal surfaces of the sleeve valve through the longitudinal slots or grooves **45** of the lower valve retainer and holds the sleeve valve in its outer or expanded position illustrated in FIGURE 1 wherein its protuberances extend into the ports **21** of the sleeve **22** and the resilient substance of which the body of the valve sleeve is formed sealingly engages the annular seat surfaces **84** about the ports. The external surface of the portions of the sleeve valve about the ports and below the lower end portions of the upper valve retainer is held out of engagement with the internal surface of the sleeve **22** since outward movement of such portions of the sleeve valve is now limited by the inserts **80**.

The valve is then connected in a string of tubing to constitute a section thereof by means of the usual coupling collars **12** and is lowered with the string of tubing into the well casing of the well. A suitable barrier or well packer (not shown) closes the annular space between the well casing and the string of tubing above the lower open end (not shown) of the tubing and above the producing earth formation. Oil or other liquids or fluids from such producing earth formations enter into the open end of the tubing and rise in the tubing to a level predetermined by the formation pressure.

The formation liquid in the tubing cannot flow outwardly through the gas lift valve because the sleeve valve **24** is now in its expanded closed position and in addition because the check valve **50** prevents any outward flow through the ports **23** of the valve housing.

If the formation pressure is such that the well fluids will not flow upwardly to the surface through the tubing, gas or air, hereinafter referred to as gas generally, is introduced into the annular space or annulus between the string of tubing and the casing at the surface in order for the gas to be injected through the gas lift valve into the column of fluids in the tubing above the gas lift valve. The pressure of the lifting gas in the annulus is raised to a predetermined pressure which is higher than the pressure of the gas in the charge chamber **17**. The sleeve valve, however, will remain in its expanded closed position since the total area of the protuberances on which the pressure of the lifting gas exerts a force on the inserts tending to move them inwardly is smaller than the total area of the inserts on which the pressure of the fluid in the chamber **17** exerts a force tending to move the inserts radially outwardly as long as the hydrostatic pressure in the tubing at the gas lift valve, which exerts a force on the areas of the external surfaces of the rigid inserts lying outwardly of the lines of sealing engagement of the protuberances with the seat surfaces **84**, is below a predetermined valve.

The column of liquids in the tubing then rises to a predetermined height above the gas lift valve at which the force of the hydrostatic pressure of the column of liquid exerted on the external surfaces of the inserts, when added to the force exerted thereon by the lifting gas in the annulus acting on the areas of the inserts within the lines of sealing engagement of the protuberances with the seat surfaces **84**, is sufficiently great to move the inserts inwardly and contract the sleeve valve radially inwardly. As the protuberances **83** are moved inwardly and open the ports **21**, the lifting gas flows inwardly from the annulus through the lateral ports **23** of the housing, the check valve flexing inwardly to permit such flow of the gas into the outer annular passage **18**, and thence through the ports **21** and the inner annular flow passage **16** and the mandrel ports **20** into the tubing. As the protuberances **83** are moved out of sealing engagement with the seat surfaces **84**, all external surfaces of the inserts as well as the external surface of the sleeve valve body, are exposed to the pressure of the gas from the annulus which, being substantially higher than the pressure of the gas in the charge chamber **17**, holds the sleeve valve in its retracted or open position.

As the lifting gas flows upwardly into the tubing, it causes the column of liquid to move upwardly in the tubing. As the well fluids are discharged from the tubing at the surface of the well, the pressure in the tubing above the valve decreases and the rate of flow of lifting gas through the valve increases. Since the ports **21** have a substantially smaller total orifice than the total orifice of the mandrel ports **20**, a pressure differential is created across the ports **21** and the pressure within the inner annular flow passage **16** decreases below the pressure of the charge of gas in the chamber **17** and the force of the gas in the charge chamber **17** again moves the sleeve outwardly to its expanded position wherein the protuberances **83** again sealingly engage the seat surfaces **84** of the inner sleeve about the ports **21**. The pressure of the gas in the annulus may also decrease as it flows into the tubing thus reducing the force exerted on the sleeve valve by the lifting gas. When the ports **21** are again closed, the sleeve valve will remain at its expanded position until the column of liquids in the tubing again rises to the predetermined height. It will thus be apparent that the valve will operate or open intermittently as long as the pressure in the annulus is at or above a predetermined value each time the column of well liquids rises to a predetermined height in the tubing above the gas lift valve.

Any time the annulus pressure is lower than that of the tubing, the check valve **50** prevents flow of the well fluids from the tubing through the gas lift valve to the annulus. It will thus be apparent that the valve **20** will open to permit flow of fluids therethrough only when the pressure in the annulus or exteriorly of the valve is greater than the pressure in the tubing and the combined force of the annulus pressure and the hydrostatic pressure in the tubing at the valve exerted on the inserts exceeds the force exerted thereon by the force of the pressure in the charge chamber.

It will now be seen that when the sleeve valve is in its closed position the total area of the rigid inserts exposed to the pressure from the exterior of the housing is relatively small compared to the total area of the inserts on which the pressure from the tubing exerts a force tending to move the inserts inwardly so that the valve opens and closes primarily in response to the tubing pressure and therefore may be termed a tubing pressure responsive valve.

It will now be seen that a new and improved gas lift valve has been illustrated and described which includes a tubular body or mandrel **11**, a housing disposed on the

mandrel and providing an annular flow passage **16** which opens at longitudinally spaced locations to the interior of the mandrel and to the exterior of the housing by means of the ports **20** and **21**, respectively, that a closure or resilient tubular valve member or sleeve valve **24** is disposed in the annular passage and has protuberances which are extendable into the ports **21** to sealingly close the ports, and that the protuberances are provided by rigid inserts **80** embedded in the tubular body **62** of the sleeve valve which extend inwardly of the internal surfaces of the housing, such as that of the inner sleeve **19**, in which the ports **21** are provided, having relatively large areas exposed to the pressure from the tubing communicated to the annular passage through the ports **20** which exerts a force on the inserts tending to move the inserts and the sleeve valve inwardly to open position but that only small areas of the protuberances are exposed to the pressure from the exterior of the ports **18** which thus acts on relatively small areas of the rigid inserts tending to move them and the sleeve valve inwardly.

It will further be seen that the housing and the mandrel provide a charge chamber which is filled with a charge of gas under pressure which pressure is transmitted to the internal surfaces of the valve and thus biases the sleeve valve radially outwardly toward its closed position.

Referring now particularly to FIGURES 8 and 9 of the drawings, the gas lift valve **100** includes a tubular mandrel **101** externally threaded at its opposite end portions whereby it is connectable between and to upper and lower tubing sections T–**1** and T–**2** of a string of tubing to constitute a section of the string of tubing by means of the usual coupling collars **12**. A tubular housing **104** is disposed on the mandrel intermediate its ends and provides a longitudinally extending space or chamber **105** which is divided into an upper annular flow passage **106** and a lower annular charge chamber **107**. The upper end of the annular flow passage is in communication with the longitudinal flow passage **109** of the mandrel by means of a plurality of lateral ports **110** thereof. The lower end of the annular flow passage communicates with the exterior of the housing through a plurality of ports **111** thereof. The total effective orifice of the housing ports **111** is substantially smaller than the effective total orifice of the mandrel ports **110** in order that a pressure differential may be created between the annular flow passage and the exterior of the housing when gas flows through the ports and the annular passage from the exterior of the housing into the longitudinal flow passage **109** of the mandrel. Flow of fluids through the annular flow passage is controlled by a sleeve valve **114** biased radially outwardly toward expanded closed position closing the ports **21** by a charge of compressed gas in the chamber **107**.

The housing **104** includes an annular bottom section **115** rigidly secured to the mandrel, as by a weld **115***a*, and an intermediate section **116** whose lower end telescopes over the upper reduced portion **117** of the bottom section and is rigidly secured thereto, as by the weld **118**. The upper end of the intermediate housing section **116** extends over the lower reduced portion **119** of a lower valve retainer **120** and is rigidly secured thereto, as by the weld **121**. The top section **122** of the housing telescopes over the upper portion of the lower valve retainer and its downward movement thereon is limited by the engagement of its annular bottom end shoulder with the upwardly facing annular shoulder **123** of the valve retainer. Upward movement of the top housing section on the mandrel is limited by a retainer ring **124** threaded on the upper end portion of the mandrel which engages the top housing section. The top housing section has an internal annular flange **125** provided with an internal annular recess in which is disposed an O-ring **126** which seals between the top housing section and the mandrel above the mandrel ports **110**. The lower valve retainer **120** has an external annular recess in which is disposed an O-ring **128** which seals between the retainer and the top housing section.

The lower portion of the resilient tubular body **132** of the sleeve valve **114** extends between the internal surfaces of the top housing section and the external annular surface **133** of the lower valve retainer above its annular upwardly facing shoulder **134**. The valve retainer has a plurality of longitudinal internal slots **136** by means of which the pressure of the fluid in the charge chamber is communicated to the internal surfaces of the sleeve valve. Fluid under pressure is introducible into the charge chamber **107** through the inlet port **138** of the bottom housing section which is closeable by a plug **139** threaded in the outer enlarged portion of the inlet port. The upper surface of the lower valve retainer **142** curves upwardly and inwardly to support the body **132** of the sleeve when the sleeve valve is in its retracted position.

An upper annular valve retainer **143** is secured to the mandrel **111** by means of transverse pins **144** in the same manner as the valve retainer **70** of the valve **10** is secured to the mandrel **11**. The upper end portion of the tubular sleeve valve has an internal flange **145** which extends into an annular external recess **146** of the mandrel and is held against outward movement by the engagement of the internal annular surface **148** of the upper valve retainer below its downwardly facing shoulder **149**. The bottom annular surface **150** of the upper retainer extends downwardly and outwardly to help support the tubular body **132** of the sleeve valve when the sleeve valve is in its fully expanded position.

A check valve **153** disposed in the annular flow passage **106** below the mandrel ports **110** has an internal flange received in the external annular recess **154** of the mandrel and is held against outward displacement therefrom by the engagement of the external surface of its lower end portion with the internal annular surface **155** of the upper valve retainer above its annular shoulder **156**. The upwardly and outwardly extending annular top surface **157** of the retainer supports the check valve whose top annular lip portion **158** is engageable with the internal surfaces of the top housing section immediately above the upper valve retainer. The valve retainer has a plurality of longitudinal circumferentially spaced slots **160** to permit flow therepast through the annular flow passage **106** of the valve.

The sleeve valve **114** has a plurality of circumferentially spaced circular substantially rigid reinforcing inserts **162** embedded therein whose central semi-spherical bosses **163** provide the body **132** of the sleeve valve with similarly shaped protuberances **164**. The protuberances extend into the ports **111** and engage the annular seat surfaces **165** of the top housing section extending about the ports to close the ports when the sleeve valve is in its outer expanded or closed position illustrated in FIGURE 8. The radii of curvature of the protuberances and bosses are of such dimension that the external surfaces of the resilient sleeve are held out of engagement with the internal surfaces of the upper housing section about the ports **111**.

It will be seen that the sleeve valve **114** is identical in structure to the sleeve valve **24** of the valve **10** and functions in the same manner.

It will now be apparent that the valve **100** functions in the same manner as the valve **10** to control flow of lifting gas into the tubing string to aid in lifting the well liquids to the surface. The tubular sleeve valve **114** is moved to its contracted open position to permit flow of the lifting gas through the annular passage **106** when the pressure of the lifting gas exteriorly of the valve is at a predetermined value, higher than the pressure of the charge of gas in the charge chamber **107**, and the column of well fluids or liquids in the tubing above the valve attains a predetermined height so that the combined force exerted on the inserts by the lifting gas from

the exterior of the valve and by the hydrostatic pressure of the column of well fluids in the tubing moves the sleeve valve inwardly to its open position against the force exerted on the sleeve valve by the pressure of the charge of gas in the charge chamber **107**. Once the sleeve valve moves inwardly to its open position, the pressure of the lifting gas from the exterior exerted on the whole external area of the external surfaces of the rigid inserts **162** holds the annular sleeve valve in its open position until the column or slug of liquids moves out of the tubing at the surface and the decrease of pressure in the tubing caused by this decrease in tubing pressure and by the pressure differential between the annular passage **106** and the exterior of the valve created due to the difference in the total effective orifices of the ports **111** and the ports **110** permits the force exerted by the charge of gas in the charge chamber on the inserts to move the sleeve valve back to its open position.

The check valve **153** prevents flow of fluid from the tubing through the gas lift valve but permits the pressure from the tubing to be communicated therepast to the external surfaces of the sleeve valve since the inherent external diameter of its lip **158** is somewhat smaller than the internal diameter of the top housing section. It will be apparent that whenever any fluid flow at any appreciable rate takes place downwardly through the flow passage **106**, the lip **158** of the check valve is moved outwardly and into sealing engagement with the top housing section. It will now be apparent that the valve **100** functions in the same manner as the valve **10** to control flow of the lifting gas into the tubing.

Referring now particularly to FIGURE 10 of the drawing, the gas lift valve **200** includes a tubular mandrel **201** which is externally threaded at its opposite end portions and is thus connectable in a string of tubing to constitute a section thereof by means of the usual coupling collars in the same manner as the mandrels **11** and **101** of the gas lift valve **10** and **100**. A tubular housing **204** is disposed on the mandrel intermediate its ends and provides a longitudinally annular extending space **205** which is divided into an upper annular flow passage **206** and a lower annular charge chamber **207**. The lower end of the annular flow passage is in communication with the longitudinal flow passage **209** of the mandrel by means of a plurality of circumferentially spaced lateral ports **210** thereof. The upper end of the annular flow passage communicates with the exterior of the housing through a plurality of ports or slots **211** thereof. Flow of fluids through the annular flow passage is controlled by a sleeve valve **214** which is biased toward its closed position closing the ports **210** by a charge of compressed gas in the chamber **207**.

The housing includes an annular top section **216** rigidly secured to the mandrel, as by the weld **217**, and which is provided with the lateral ports **211**. An intermediate section **218** of the housing telescopes over the lower end portions of the upper section, the upward telescoping movement of the intermediate section relative to the top housing section is limited by the engagement of its top annular end shoulder **220** with the downwardly facing shoulder **221** of the top section. An O-ring **223** disposed in a suitable external annular recess of the top housing section between the top and intermediate sections. The bottom housing section **224** has an internal annular flange **225** provided with an internal annular recess in which is disposed an O-ring **226** which seals between the flange and the mandrel. The flange **225** is provided with an inlet port **228**, closable by a plug **229** threaded in its enlarged outer end, through which a gas under pressure is introduced into the charge chamber **205**. The intermediate housing section telescopes over the upper reduced end portion of the bottom section and is rigidly secured thereto, as by a weld **230**. A retainer ring **231** threaded on the lower end portion of the mandrel engages the bottom housing section to limit its downward movement relative to the mandrel and to the top section.

The lower portion of the resilient tubular body **232** of the sleeve valve **214** is secured to the mandrel by a suitable clamp ring **233**. Downward movement of the resilient tubular body is limited by the engagement of its bottom annular end shoulder with the upwardly facing shoulder **233** of the external annular flange **234** of the mandrel. The mandrel immediately above its flange **234** may be provided with external ribs or the like which engage the internal surfaces of the resilient body to help prevent longitudinal displacement of the lower portion of the resilient body on the mandrel. If desired, of course, the lower end portion of the tubular body may be bonded or adhesively secured to the mandrel. The upper end portion of the resilient tubular body **232** extends between the internal surfaces of the intermediate housing section and the external surface **236** of the reduced dependent lower portion **237** of the top housing section below the downwardly facing annular shoulder **233** thereof.

An annular support member **240** is rigidly secured to the mandrel, as by welding or the like, and is provided with a downwardly and inwardly beveled support surface **241** which is engageable by the internal surfaces of the resilient sleeve which engage the internal surfaces of the resilient tubular body to limit its inward movement. The valve support member **240** is provided with a plurality of circumferentially spaced longitudinally extending slots **243** which permit flow of fluid therepast through the annular passage **206**.

The sleeve valve **214** is provided with a plurality of circular substantially rigid reinforcing inserts **245** which have inwardly extending bosses **246**. The bosses cause the sleeve valve to have a plurality of substantially semispherical inwardly extending protuberances **248**. The protuberances **248** are adapted to sealingly engage the annular seat surfaces **250** of the mandrel about the lateral ports **210** of the mandrel when the sleeve valve is in its closed position, FIGURE 10. The inserts **245** cause the internal surfaces of the sleeve to be spaced from the external surface of the mandrel adjacent the lateral ports **210** thereof so that the pressure from the exterior of the housing is communicated to these internal surfaces even when the sleeve valve is in its closed position through the ports **211**, the annular flow passage **206** and the slots **243** of the support **240**.

It will be apparent that the valve **200** functions in a manner similar to that of the valves **10** and **100** when it is connected in a tubing string to facilitate flow of well liquids to the surface. The charge of compressed gas in the charge chamber **207** holds the sleeve valve in its closed position as long as the pressure of the lifting gas in the annulus of the well is below a first predetermined value and the hydrostatic pressure in the tubing exerted on the inserts through the ports **210** is below a second predetermined value which is lower than the first predetermined value. The sleeve valve **214** is moved to its open position to permit flow of the lifting gas through the annular passage **206** when the pressure of the lifting gas exteriorly of the valve is at the first predetermined value, higher than the pressure of the charge of gas in the charge chamber **207**, and the column of well fluids or liquids in the tubing above the valve attains a predetermined height so that the combined force exerted on the inserts by the lifting gas from the exterior of the valve and by the hydrostatic pressure of the column of well fluids in the tubing moves the sleeve valve outwardly to its open position against the force exerted on the sleeve valve by the pressure of the charge of gas in the charge chamber **207**. Once the sleeve valve is moved inwardly to its open position, the pressure of the lifting gas from the annulus is exerted over the full internal surfaces of the rigid inserts **245** and holds the annular sleeve valve in its open position until the column or slug of liquids moves out of the tubing at the surface and the flow of lifting gas from the annulus into the tubing

causes the pressure of the lifting gas in the annulus to drop below the pressure of the charge of gas in the charge chamber **207** whereupon the sleeve valve is again moved to its closed position. The lifting gas introduced into the tubing through the gas lift valve during the time the sleeve valve is in its open position aids in lifting or flowing the column of well fluids to the surface of the well.

The pressure of the lifting gas introduced into the annulus of the valve is thereafter increased again to the first predetermined value and when the column of well fluids in the tubing again reaches the predetermined height, the sleeve valve is again moved to its open position.

The introduction of the lifting gas into the well annulus between the string of tubing and the internal surfaces of the well bore may be controlled by a suitable intermitter valve which periodically opens to permit lifting gas to be introduced into the annulus.

It will now be apparent that since the area of the inserts on which the force of the lifting gas is exerted and biases the valve to its open position is increased by only a small amount when the sleeve valve is open, by the addition of the surfaces thereof previously lying within the lines of sealing engagement of the protuberances with the seat surfaces **250** of the mandrel when the sleeve valve is in its closed position, the difference or spread between the value of the pressure of the lifting gas at which the sleeve valve is moved to its open position and the value thereof at which the sleeve valve moves to its closed position is quite small in contrast to that of the valves **10** and **100** wherein only a small area of the valve inserts is exposed to the pressure of the lifting gas when the valve is in its closed position and a relatively large area thereof is exposed to its pressure when the valve is in its open position. As a result, the gas lift valve **200** will close when the pressure of the lifting gas drops only a very small degree from the value thereof at which the gas lift valve opens while the gas lift valves **10** and **100** will close only when the pressure of the lifting gas drops a great degree from the value thereof at which these gas lift valves open. The choice of which valve **10**, **100** or **200** to employ in a particular well will depend on the particular flow and pressure characteristics of the well.

It will be apparent that the valve **200** may be provided with a check valve, similar to the check valve **50** of the valve **10**, to prevent fluid flow to the exterior of the valve through the ports **211**.

It will now be apparent that in all three forms of the valve embodying the invention, the valve opens when the pressure of the lifting gas in the annulus of the well exceeds a first predetermined value above the value of the pressure of the charge of gas contained in its charge chamber and the hydrostatic pressure exerted on the sleeve valve by a column of well fluids in the tubing exceeds a second predetermined value which is lower than the first predetermined value.

It will further be seen that the valves **10** and **100** move from their open to their closed positions when the pressure within the tubing decreases and the pressure differential between the tubing and the annulus increases as the column of well fluids is expelled from the tubing at the well at the surface and that the valve **200** moves from its open to its closed position whenever the pressure of the lifting gas in the annulus of the well drops below the value of the pressure of the charge of gas in the charge chamber.

It will further be seen that the spread between the values of the pressure of the lifting gas, for a predetermined hydrostatic pressure condition within the tubing, at which the valve opens and closes may be varied by varying the difference between areas of the inserts exposed to the pressure of the lifting gas when the valve is in its open and closed positions.

It will now further be seen that the gas lift valve is provided with a new and improved tubular closure member or sleeve valve having protuberances provided by rigid inserts which may extend radially outwardly as in the sleeve valves **24** and **114** or inwardly as in the sleeve **214** to provide areas exposed to the pressure of the lifting gas and of the well fluids in the tubing.

The foregoing description of the invention is explanatory only, and changes in the details of the construction illustrated may be made by those skilled in the art, within the scope of the appended claims, without departing from the spirit of the invention.

What is claimed and desired to be secured by Letters Patent is:

1. A valve including: a tubular mandrel; a tubular housing disposed on said mandrel and providing with said mandrel an annular longitudinally extending chamber about said mandrel; a tubular flexible sleeve valve disposed in said annular chamber and dividing said annular chamber into an annular flow passage and a charge chamber, said housing and said mandrel having lateral ports opening to said flow passage at longitudinally spaced locations, said sleeve valve being biased by the pressure of a charge of gas in said charge chamber toward engagement with one of said mandrel and said housing to close the ports thereof; and reinforcing means in said flexible sleeve providing protuberances thereon each engageable with one of said lateral ports of said one of said mandrel and said housing to close said port; said reinforcing means having a portion surrounding said protuberance holding the portion of said sleeve adjacent said protuberance out of engagement with that portion of said one of said mandrel and said housing adjacent said port to admit fluid pressure between the sleeve and said one of said mandrel and said housing adjacent said port.

2. A valve including: a tubular mandrel; a tubular housing disposed on said mandrel and providing with said mandrel an annular longitudinally extending chamber about said mandrel; a tubular flexible sleeve valve disposed in said annular chamber and dividing said annular chamber into an annular flow passage and a charge chamber, said housing and said mandrel having lateral ports opening to said flow passage at longitudinally spaced locations, said sleeve valve being biased by the pressure of a charge of gas in said charge chamber toward engagement with one of said mandrel and said housing to close the ports thereof, said sleeve valve including a resilient tubular body and a plurality of spaced substantially rigid inserts embedded in said tubular body providing said tubular body with radially extending protuberances extendable into the ports of said one of said mandrel and said housing and sealingly engageable with said one of said mandrel and said housing at said ports, said inserts each having a portion surrounding said protuberance holding the portion of said sleeve adjacent said protuberance out of engagement with that portion of said one of said mandrel and said housing adjacent said ports to admit fluid pressure between said sleeve and said one of said mandrel and said housing adjacent said ports.

3. A valve including: a tubular mandrel; a tubular housing disposed on said mandrel and providing with said mandrel an annular longitudinally extending chamber about said mandrel; tubular flexible sleeve valve disposed in said annular body and dividing said annular chamber into an annular flow passage and a charge chamber, said housing and said mandrel having lateral ports opening to said flow passage at longitudinally spaced locations, said sleeve valve being biased by the pressure of a charge of gas in said charge chamber toward engagement with one of said mandrel and said housing to close the ports thereof; said sleeve valve including a resilient tubular body and a plurality of spaced rigid inserts embedded in said body, said inserts having radially extending arcuate bosses, said bosses providing said tubular body with radially extending protuberances movable into the ports of one of said mandrel and said housing and seal-

ingly engageable with said one of said mandrel and said housing to close the ports thereof, said rigid inserts having a lateral substantially rigid portion surrounding said protuberances holding the portion of said sleeve adjacent said protuberances out of engagement with that portion of said one of said mandrel and said housing adjacent said ports to provide an area on which when said sleeve valve is in said closed position the fluid pressure communicated to said passage through the ports of one of said mandrel and said housing exerts a force tending to move the sleeve valve to its open position and an area on which the fluid pressure communicated through the ports of the other of said mandrel and said housing exerts a force tending to move the sleeve valve to its open position.

4. A valve including: a tubular mandrel; a tubular housing disposed on said mandrel and providing with said mandrel an annular longitudinally extending chamber about said mandrel; tubular flexible sleeve valve disposed in said annular body and dividing said annular chamber into an annular flow passage and a charge chamber, said housing and said mandrel having lateral ports opening to said flow passage at longitudinally spaced locations, said sleeve valve being biased by the pressure of a charge of gas in said charge chamber toward engagement with one of said mandrel and said housing to close the ports thereof; said sleeve valve including a resilient tubular body and a plurality of spaced rigid inserts embedded in said body, said inserts having radially extending arcuate bosses, said bosses providing said tubular body with radially extending protuberances movable into the ports of one of said mandrel and said housing and sealingly engageable with said one of said mandrel and said housing to close the ports thereof, said rigid inserts having a lateral substantially rigid portion surrounding said protuberances holding the portion of said sleeve adjacent said protuberances out of engagement with that portion of said one of said mandrel and said housing adjacent said ports to provide an area on which when said sleeve valve is in said closed position the fluid pressure communicated to said passage through the ports of one of said mandrel and said housing exerts a force tending to move the sleeve valve to its open position and an area on which the fluid pressure communicated through the ports of the other of said mandrel and said housing exerts a force tending to move the sleeve valve to its open position, said areas of said inserts on which the force of the fluid pressures communicated through the ports of said one of said mandrels and said housing exerts a force tending to move the sleeve valve to open position when the sleeve valve is in its closed position being substantially greater than said areas thereof on which the pressure communicated through the ports of said other of said mandrel and said housing exerts a force tending to move the sleeve valve to its open position.

5. A valve including: a tubular mandrel; a tubular housing disposed on said mandrel and providing with said mandrel an annular longitudinally extending chamber about said mandrel; a tubular flexible sleeve valve disposed in said annular chamber and dividing said annular chamber into an annular flow passage and a charge chamber, said housing having lateral ports opening to said flow passage through which the pressure from the exterior of the valve is communicated to said flow passage, said mandrel having ports opening from the interior thereof to said flow passage, said ports of said housing and said mandrel being spaced, said sleeve valve being biased by the pressure of a charge of gas in said charge chamber toward engagement with said mandrel at the location of the said ports of said mandrel for closing the ports thereof, said sleeve valve including a resilient tubular body and a plurality of spaced rigid inserts embedded in said body and having radially inwardly extending bosses whereby said tubular body is provided with radially inwardly extending protuberances movable into the ports of said mandrel and sealingly engageable with said mandrel, said inserts having a substantially rigid laterally projecting portion surrounding said protuberances holding the portion of said sleeve adjacent said protuberances out of engagement with that portion of said mandrel adjacent said ports to provide surfaces on which fluid pressure from the exterior of the housing exerts a force tending to move the inserts radially outwardly of the mandrel, said bosses when said protuberances sealingly engage said mandrel having surfaces on which fluid pressure from said mandrel exerts a force tending to move the inserts radially outwardly of the mandrel.

6. A valve including: a tubular mandrel; a tubular housing disposed on said mandrel and providing with said mandrel an annular longitudinally extending chamber about said mandrel; a tubular flexible sleeve valve disposed in said annular chamber and dividing said annular chamber into an annular flow passage and a charge chamber, said housing having lateral ports opening to said flow passage through which the pressure from the exterior of the valve is communicated to said flow passage, said mandrel having ports opening from the interior thereof to said flow passage, said ports of said housing and said mandrel being spaced, said sleeve valve being biased by the pressure of a charge of gas in said charge chamber toward engagement with said mandrel at the location of the said ports of said mandrel for closing the ports thereof, said sleeve valve including a resilient tubular body and a plurality of spaced rigid inserts embedded in said body and having radially inwardly extending bosses whereby said tubular body is provided with radially inwardly extending protuberances movable into the ports of said mandrel and sealingly engageable with said mandrel, said inserts when said protuberances sealingly engage said mandrel to close the ports thereof having portions surrounding said protuberances holding the portion of said sleeve adjacent said protuberances out of engagement with that portion of said mandrel adjacent the ports and providing an area of said sleeve spaced outwardly of said mandrel and having surfaces on which fluid pressure from the exterior of the housing exerts a force tending to move the inserts radially outwardly of the mandrel, said bosses when said protuberances sealingly engage said mandrel having surfaces on which fluid pressure from said mandrel exerts a force tending to move the inserts radially outwardly of the mandrel, said surfaces of said inserts on which fluid pressure from the exterior of the housing exerts a force tending to move the inserts radially outwardly of the mandrel having areas substantially greater than the areas of the surfaces of said bosses on which fluid pressure from said mandrel exerts a force tending to move the inserts radially outwardly of the mandrel.

7. A valve including: a tubular mandrel; a tubular housing disposed on said mandrel and providing with said mandrel an annular longitudinally extending chamber about said mandrel; a tubular flexible sleeve valve disposed in said annular chamber and dividing said annular chamber into an annular flow passage and a charge chamber, said housing having lateral ports opening to said flow passage through which fluid pressure from the exterior of the valve is communicated to said flow passage, said mandrel having ports opening from the interior thereof to said flow passage, said ports of said housing and said mandrel being spaced, said sleeve valve being biased by the pressure of a charge of gas in said charge chamber toward sealing engagement with said housing at the location of said ports of said housing for closing the ports thereof, said sleeve valve including a resilient tubular body and a plurality of spaced substantially rigid inserts embedded in said body and having radially outwardly extending bosses whereby said tubular body is provided with radially outwardly extending protuberances movable into the ports of said housing and sealingly engageable with said housing and substantially rigid portions surrounding said protuberances holding the portion of said

sleeve adjacent said protuberances out of engagement with said housing, whereby said inserts when said protuberances sealingly engage said housing have portions thereof spaced inwardly of said housing providing surfaces on which fluid pressure in the flow passage and from the interior of the mandrel exerts a force tending to move the inserts radially inwardly of the housing toward open position to move the inserts radially inwardly relative to the housing, said bosses when said protuberances sealingly engage said housing having surfaces on which fluid pressure from the exterior of said housing exerts a force tending to move the inserts radially inwardly of the housing toward open position.

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