



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<b>(21) International Application Number:</b> PCT/GB98/02242  <b>(22) International Filing Date:</b> 21 July 1998 (21.07.98)  <b>(30) Priority Data:</b> 08/898,567              21 July 1997 (21.07.97)              US  <b>(71) Applicant (for all designated States except MN):</b> PETROLEUM ENGINEERING SERVICES INC. [US/US]; 1442 Lakefront Circle, The Woodlands, TX 77380 (US).  <b>(71) Applicant (for MN only):</b> PETROLEUM ENGINEERING SERVICES LIMITED [GB/GB]; Howe Moss Avenue, Kirkhill Industrial Estate, Dyce, Aberdeen AB21 0GP (GB).  <b>(72) Inventors:</b> BOULDIN, Brett, Wayne; 707 Creek Forest Circle, Spring, TX 77380 (US). ARIZMENDI, Napoleon; 11910 W. Presley, Magnolia, TX 77355 (US).  <b>(74) Agent:</b> MURGITROYD & COMPANY; 373 Scotland Street, Glasgow G5 8QA (GB).	<b>(81) Designated States:</b> AU, BR, CA, MN, NO, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>Without international search report and to be republished              upon receipt of that report.</i>	
<b>(54) Title:</b> VARIABLE CHOKE FOR USE IN A SUBTERRANEAN WELL		
<b>(57) Abstract</b>  <p>A flow control apparatus and associated methods of using provide enhanced longevity and reliability without requiring complex mechanisms. In a described embodiment, a choke for use within a subterranean well has a choke member set which may be opened by manipulation of an inner tubular cage. The inner cage is displaced from within an outer sleeve, which restricts fluid flow through ports formed through a sidewall portion of the inner cage. As the inner cage is progressively withdrawn from within the sleeve, the fluid flow through the ports is decreasingly restricted by the sleeve.</p>		

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1     "Variable Choke for Use in a Subterranean Well"

2

3     The present invention relates generally to apparatus  
4     utilised to control fluid flow in a subterranean well  
5     and, in an embodiment described herein, more  
6     particularly provides a choke for selectively  
7     regulating fluid flow into or out of a tubing string  
8     disposed within a well.

9

10    In a subsea well completion it is common for the well  
11    to be produced without having a rig or production  
12    platform on site. In this situation, it is well known

1 that any problems that occur with equipment or other  
2 aspects of the completion may require a rig to be moved  
3 on site, in order to resolve the problem. Such  
4 operations are typically very expensive and should be  
5 avoided if possible.

6  
7 An item of equipment needed, particularly in subsea  
8 completions, is a flow control apparatus which is used  
9 to throttle or choke fluid flow into a production  
10 tubing string. The apparatus would be particularly  
11 useful where multiple zones are produced and it is  
12 desired to regulate the rate of fluid flow into the  
13 tubing string from each zone. Additionally, regulatory  
14 authorities may require that rates of production from  
15 each zone be reported, necessitating the use of the  
16 apparatus or other methods of determining and/or  
17 controlling the rate of production from each zone.  
18 Safety concerns may also dictate controlling the rate  
19 of production from each zone.

20  
21 Such an item of equipment would also be useful in  
22 single zone completions. For example, in a single  
23 wellbore producing from a single zone, an operator may  
24 determine that it is desirable to reduce the flow rate  
25 from the zone into the wellbore to limit damage to the  
26 well, reduce water coning and/or enhance ultimate  
27 recovery.

28 Downhole valves, such as sliding side doors, are  
29 designed for operation in a fully closed or fully open  
30 configuration and, thus, are not useful for variably  
31 regulating fluid flow therethrough. Downhole chokes  
32 typically are provided with a fixed orifice which  
33 cannot be closed. These are placed downhole to limit  
34 flow from a certain formation or wellbore.  
35 Unfortunately, conventional downhole valves and chokes  
36 are also limited in their usefulness because

1 intervention is required to change the fixed orifice or  
2 to open or close the valve.

3  
4 What is needed is a flow control apparatus which is  
5 rugged, reliable, and long-lived, so that it may be  
6 utilized in completions without requiring frequent  
7 service, repair or replacement. To compensate for  
8 changing conditions, the apparatus should be adjustable  
9 without requiring slickline, wireline or other  
10 operations which need a rig for their performance, or  
11 which require additional equipment to be installed in  
12 the well. The apparatus should be resistant to  
13 erosion, even when it is configured between its fully  
14 open and closed positions, and should be capable of  
15 accurately regulating fluid flow.

16  
17 Such a downhole variable choking device would allow an  
18 operator to maximize reservoir production into the  
19 wellbore. It would be useful in surface, as well as  
20 subsea, completions, including any well where it is  
21 desired to control fluid flow, such as gas wells, oil  
22 wells, and water and chemical injection wells. In sum,  
23 in any downhole environment for controlling flow of  
24 fluids.

25  
26 It is accordingly an object of the present invention to  
27 provide such a flow control apparatus which permits  
28 variable downhole flow choking as well as the ability  
29 to shut off fluid flow, and associated methods of  
30 controlling fluid flow within a subterranean well.

31

### 32 **SUMMARY OF THE INVENTION**

33

34 In carrying out the principles of the present  
35 invention, in accordance with an embodiment thereof, an  
36 apparatus is provided which is a choke for use within a

1 subterranean well. The described choke provides  
2 ruggedness, simplicity, reliability and longevity in  
3 regulating fluid flow into or out of a tubing string  
4 within the well.

5  
6 In broad terms, a choke is provided which includes a  
7 tubular inner cage, an outer housing and a choke member  
8 set. The cage is slidingly disposed within the housing  
9 and the choke member set is carried externally on the  
10 cage. Manipulation of the cage by a conventional  
11 actuator or shifting tool causes the choke member set  
12 to partially open, fully open, and close as desired.

13  
14 The choke member set utilizes a design which both  
15 impedes erosion and wear of the choke components, and,  
16 in combination with the cage, permits commingling of  
17 fluids produced from multiple zones of the well, or  
18 control of fluids injected into multiple zones.  
19 Commingling of fluids produced, or control of fluids  
20 injected, may be precisely regulated by manipulation of  
21 the cage with the actuator.

22  
23 These and other aspects, features, objects, and  
24 advantages of the present invention will be more fully  
25 appreciated following careful consideration of the  
26 detailed description and accompanying drawings set  
27 forth hereinbelow.

28  
29 **BRIEF DESCRIPTION OF THE DRAWINGS**

30  
31 FIGS. 1A-1B are quarter-sectional views of successive  
32 axial portions of a choke embodying principles of the  
33 present invention, the choke being shown in a  
34 configuration in which it is initially run into a  
35 subterranean well attached to an actuator and  
36 interconnected in a production tubing string;

1 FIG. 2 is a quarter-sectional view of an axial  
2 portion of the choke of FIGS. 1A-1B, the choke  
3 being shown in a configuration in which a choke  
4 member set has been partially opened;  
5 FIG. 3 is a quarter-sectional view of an axial  
6 portion of the choke of FIGS. 1A-1B, the choke  
7 being shown in a configuration in which the choke  
8 member set has been fully opened;  
9 FIG. 4 is an enlarged quarter-sectional view of an  
10 axial portion of the choke of FIGS. 1A-1B, the  
11 choke being shown in a configuration in which  
12 fluid flow through a port of the choke member set  
13 is partially restricted;  
14 FIGS. 5A-5C are quarter-sectional views of  
15 successive axial portions of another choke  
16 embodying principles of the present invention, the  
17 choke being shown in a configuration in which it  
18 is initially run into a subterranean well attached  
19 to an actuator and interconnected in a production  
20 tubing string; and  
21 FIG. 6 is an elevational view of an opening formed  
22 through an outer housing of the choke of FIGS. 5A-  
23 5C, as indicated by arrows 6-6.  
24

#### 25 DETAILED DESCRIPTION

26  
27 Representatively illustrated in FIGS. 1A-1B is a choke  
28 10 which embodies principles of the present invention.  
29 In the following description of the choke 10 and other  
30 apparatus and methods described herein, directional  
31 terms, such as "above", "below", "upper", "lower",  
32 etc., are used for convenience in referring to the  
33 accompanying drawings. Although the choke 10 and other  
34 apparatus, etc., shown in the accompanying drawings are  
35 depicted in successive axial sections, it is to be  
36 understood that the sections form a continuous

1 assembly. Additionally, it is to be understood that  
2 the various embodiments of the present invention  
3 described herein may be utilized in various  
4 orientations, such as inclined, inverted, horizontal,  
5 vertical, etc., without departing from the principles  
6 of the present invention.

7  
8 The choke 10 is sealingly attached to an actuator 12, a  
9 lower portion of which is shown in FIG. 1A. In a  
10 manner which will be more fully described hereinbelow,  
11 the actuator 12 is used to operate the choke 10. The  
12 actuator 12 may be hydraulically, electrically,  
13 mechanically, magnetically or otherwise controlled  
14 without departing from the principles of the present  
15 invention. The representatively illustrated actuator  
16 12 is a SCRAMS ICV hydraulically controlled actuator  
17 manufactured by, and available from, PES, Incorporated  
18 of The Woodlands, Texas. It includes an actuator  
19 member or annular piston 14 which is axially  
20 displaceable relative to the choke 10 by appropriate  
21 hydraulic pressure applied to the actuator 12 via  
22 control lines (not shown) extending to the earth's  
23 surface.

24  
25 In a method of using the choke 10, the choke and  
26 actuator 12 are positioned within a subterranean well  
27 as part of a production tubing string 18 extending to  
28 the earth's surface. As representatively illustrated  
29 in FIGS. 1A-1B, fluid (indicated by arrows 20) may flow  
30 axially through the choke 10 and actuator 12, and to  
31 the earth's surface via the tubing string 18. The  
32 fluid 20 may, for example, be produced from a zone of  
33 the well below the choke 10. In that case, an  
34 additional portion of the tubing string 18 including a  
35 packer (not shown) would be attached in a conventional  
36 manner to a lower adaptor 22 of the choke 10 and set in

1 the well in order to isolate the zone below the choke  
2 from other zones of the well, such as a zone in fluid  
3 communication with an area 24 surrounding the choke.

4  
5 In a manner more fully described hereinbelow, the choke  
6 10 enables accurate regulation of fluid flow between  
7 the external area 24 and an internal axial fluid  
8 passage 26 extending through the choke. In another  
9 method of using the choke 10, multiple chokes may be  
10 installed in the tubing string 18, with each of the  
11 chokes corresponding to a respective one of multiple  
12 zones intersected by the well, and with the zones being  
13 isolated from each other external to the tubing string.  
14 Thus, the choke 10 also enables accurate regulation of  
15 a rate of fluid flow from each of the multiple zones,  
16 with the fluids being commingled in the tubing string  
17 18.

18  
19 It is to be understood that, although the tubing string  
20 18 is representatively illustrated in the accompanying  
21 drawings with fluid 20 entering the lower adaptor 22  
22 and flowing upwardly through the fluid passage 26, the  
23 lower connector 22 may actually be closed off or  
24 otherwise isolated from such fluid flow in a  
25 conventional manner, such as by attaching a bull plug  
26 thereto, or the fluid 20 may be flowed downwardly  
27 through the fluid passage 26, for example, in order to  
28 inject the fluid into a formation intersected by the  
29 well, without departing from the principles of the  
30 present invention. For convenience and clarity of  
31 description, the choke 10 and associated tubing string  
32 18 will be described hereinbelow as it may be used in a  
33 method of producing fluids from multiple zones of the  
34 well, the fluids being commingled within the tubing  
35 string, and it being expressly understood that the  
36 choke 10 may be used in other methods without departing

1 from the principles of the present invention.

2

3 An upper portion 16 of the choke 10 is attached to the  
4 actuator 12. As shown in FIG. 1B, the upper portion 16  
5 is integrally formed with an outer housing 28 of the  
6 actuator 12. However, it is to be understood that the  
7 choke 10 may be threadedly attached to the actuator 12,  
8 or otherwise attached thereto without departing from  
9 the principles of the present invention. In that  
10 manner, the choke 10 may be used with other actuators,  
11 attached directly to the remainder of the tubing string  
12 18, etc.

13

14 The piston 14 is attached externally about an upper  
15 generally tubular operating mandrel 30 of the choke 10.  
16 A retaining ring 32 extends radially inwardly from the  
17 piston 14 and engages an annular groove 34 formed  
18 externally on the mandrel 30. Thus, axial displacement  
19 of the piston 14 by the actuator 12 will cause a  
20 corresponding axial displacement of the mandrel 30.

21

22 The mandrel 30 is axially reciprocably and sealingly  
23 received in the actuator 12. Circumferential seals 36  
24 sealingly engage the mandrel 30 externally and permit  
25 fluid isolation between two chambers 38, 40. In this  
26 manner, it may be considered that the mandrel 30  
27 becomes a part of the actuator 12, but it is to be  
28 clearly understood that it is not necessary, in keeping  
29 with the principles of the present invention, for the  
30 mandrel 30 to form a part of the actuator 12.

31

32 To operate the choke 10, the mandrel 30 is axially  
33 displaced relative to the upper portion 16, in order to  
34 axially displace an inner axially extending and  
35 generally tubular cage member 42 relative to an outer  
36 housing 44 of the choke. The mandrel 30 is sealingly

1 interconnected to the cage 42 by shrink fitting it  
2 thereto, although any other suitable connection method,  
3 such as brazing, threading, integrally forming, etc.,  
4 may be utilized without departing from the principles  
5 of the present invention. The applicants use shrink  
6 fitting since, in the representatively illustrated  
7 embodiment of the invention, the cage 42 is made of a  
8 highly erosion resistant material, such as carbide,  
9 while the mandrel 30 is made of an alloy steel.

10

11 Axial displacement of the mandrel 30 is accomplished by  
12 applying fluid pressure to one of the chambers 38, 40  
13 to thereby apply an axially directed biasing force to  
14 the piston 14. For example, if it is desired to  
15 displace the mandrel 30 axially upward to permit fluid  
16 flow through the choke 10 or to decrease resistance to  
17 fluid flow therethrough, fluid pressure may be applied  
18 to the lower chamber 40. Conversely, if it is desired  
19 to downwardly displace the mandrel 30 to prevent fluid  
20 flow through the choke 10 or to increase resistance to  
21 fluid flow therethrough, fluid pressure may be applied  
22 to the upper chamber 38.

23

24 The housing 44 includes a series of axially elongated  
25 and circumferentially spaced apart openings 46, only  
26 one of which is visible in FIG. 1B. The openings 46  
27 are formed through a sidewall portion of the housing 44  
28 and thereby provide fluid communication between the  
29 area 24 external to the choke 10 and the interior of  
30 the housing. The housing 44 is integrally formed with  
31 the upper portion 16, and is threadedly and sealingly  
32 attached to the lower adaptor 22, with the openings 46  
33 being positioned axially between the upper portion 16  
34 and the lower adaptor.

35

36 A choke member set 48 is disposed within the outer

1 housing 44 and includes a portion of a sleeve 50  
2 received sealingly within the outer housing. As used  
3 herein, the term "choke member set" is used to describe  
4 an element or combination of elements which perform a  
5 function of regulating fluid flow. In the illustrated  
6 embodiment of the invention, the choke member set 48  
7 includes an upper portion of the sleeve 50 and portions  
8 of the cage 42, which will be more fully described  
9 hereinbelow. The applicants prefer that the choke  
10 member set 48 be configured in some respects similar to  
11 those utilized in a Master Flo Flow Trim manufactured  
12 by, and available from, Master Flo of Ontario, Canada,  
13 although other choke member sets may be utilized  
14 without departing from the principles of the present  
15 invention.

16

17 The sleeve 50 is sealingly received in the housing 44  
18 by shrink fitting it therein. Of course, other methods  
19 of sealingly attaching the sleeve 50 may be utilized  
20 without departing from the principles of the present  
21 invention. For example, the sleeve 50 could be  
22 threaded into the housing 44, brazed therein, etc.

23

24 The sleeve 50 includes an axially extending and  
25 internally inclined lip 52 adjacent an externally  
26 inclined seal surface 54. The lip 52 acts to prevent,  
27 or at least greatly reduce, erosion of the seal surface  
28 54, among other benefits. The seal surface 54 is  
29 cooperatively shaped to sealingly engage a seal surface  
30 56 internally formed on a seat 58, which is externally  
31 carried on the cage 42 and integrally formed therewith.  
32 In the configuration of the choke 10 shown in FIG. 1B,  
33 the seal surface 54 is contacting and sealingly  
34 engaging the seal surface 56. Preferably, the seal  
35 surfaces 54, 56 are formed of hardened metal or carbide  
36 for erosion resistance, although other materials may be

1 utilized without departing from the principles of the  
2 present invention. Additionally, the seat 58, which  
3 includes the seal surface 56, may be wholly or  
4 partially formed of hardened metal or carbide, and may  
5 be separately formed from the cage 42.

6  
7 The cage 42 has a set of flow ports 60, and a set of  
8 comparatively larger flow ports 62, formed radially  
9 therethrough. Each of the sets of ports 60, 62  
10 includes two circumferentially spaced apart and  
11 oppositely disposed ports, although only one of each is  
12 visible in FIG. 1B. Of course, other numbers of ports  
13 may be utilized in the flow port sets 60, 62 without  
14 departing from the principles of the present invention.  
15 In the configuration of the choke 10 shown in FIG. 1B,  
16 the upper ports 60 and lower ports 62 are radially  
17 outwardly overlaid by the sleeve 50, and the seal  
18 surfaces 54, 56 are sealingly engaged. Thus, fluid  
19 communication between the external area 24 and the flow  
20 passage 26 through the flow ports 60, 62 is prevented  
21 by the sleeve 50.

22  
23 As representatively illustrated in the accompanying  
24 drawings, the flow ports 60 are comparatively small, in  
25 order to provide an initial relatively highly  
26 restricted fluid flow therethrough when the cage 42 is  
27 displaced axially upward to permit fluid flow between  
28 the seal surfaces 54, 56, as more fully described  
29 hereinbelow. However, it is to be understood that the  
30 flow ports 60 may be otherwise dimensioned, otherwise  
31 positioned, otherwise dimensioned with respect to each  
32 other, and otherwise positioned with respect to each  
33 other, without departing from the principles of the  
34 present invention. For example, the upper flow ports  
35 60 may actually have larger or smaller diameters, may  
36 have larger or smaller diameters than the lower flow

1 ports 62, may be positioned differently on the cage 42,  
2 and may be positioned differently with respect to the  
3 lower flow ports. Similar changes may be made to the  
4 lower flow ports 62. Indeed, it is not necessary for  
5 the cage 42 to have differently configured sets of flow  
6 ports 60, 62 at all. Thus, the flow port sets 60, 62  
7 shown in the accompanying drawings are merely  
8 illustrative and additions, modifications, deletions,  
9 substitutions, etc., may be made thereto without  
10 departing from the principles of the present invention.

11

12 As shown in FIG. 1B, the cage 42 is prevented from  
13 displacing axially downward relative to the sleeve 50  
14 by axial contact between the seal surfaces 54, 56.  
15 Such axial contact may be maintained by maintaining  
16 fluid pressure in the chamber 38 of the actuator 12.  
17 It will be readily apparent to a person of ordinary  
18 skill in the art that such axial contact may also be  
19 maintained by provision of a biasing member (not  
20 shown), which applies an axially downward biasing force  
21 to the mandrel 30 or cage 42. For example, a  
22 compression spring may be installed in the chamber 38  
23 to apply a downwardly directed biasing force to the  
24 piston 14 and, therefore, to the mandrel 30. However,  
25 applicants prefer that the cage 42 not be biased into  
26 axial contact with the sleeve 50, so that the choke 10  
27 may be opened and remain open in the event that a  
28 failure should be experienced in the actuator 12. For  
29 displacement of the mandrel 30 and cage 42 in the event  
30 of such a failure, a conventional shifting profile 64  
31 is internally formed on the mandrel 30, which may be  
32 engaged by a shifting tool (not shown) conveyed on  
33 wireline, slickline, coiled tubing, etc., in a  
34 conventional manner. Of course, other profiles and  
35 methods of displacing the mandrel 30 and/or cage 42 may  
36 be utilized without departing from the principles of

1 the present invention. Additionally, other methods of  
2 maintaining the cage 42 in a desired position relative  
3 to the housing 44 may be utilized without departing  
4 from the principles of the present invention. For  
5 example, detents, etc., may be configured to  
6 cooperatively engage the cage 42 and/or housing 44.

7  
8 If the cage 42 is displaced axially upward relative to  
9 the sleeve 50 and housing 44, the seal surfaces 54, 56  
10 will disengage and fluid flow will be permitted between  
11 the external area 24 and the fluid passage 26. Thus,  
12 the choke member set 48 is selectively openable by  
13 axially displacing the cage 42 upward from its position  
14 shown in FIG. 1B. The choke member set 48 may be  
15 maintained in an open position by, for example, a  
16 latching device (not shown).

17  
18 Referring additionally now to FIG. 2, an axial portion  
19 of the choke 10 is representatively illustrated in a  
20 configuration in which the upper flow ports 60 are  
21 exposed to direct fluid flow between the area 24 and  
22 the fluid passage 26. In this configuration, the cage  
23 42 has been axially upwardly displaced relative to the  
24 housing 44 and sleeve 50. The seal surfaces 54, 56 are  
25 no longer sealingly engaged, thus permitting fluid  
26 communication between the area 24 and the fluid passage  
27 26.

28  
29 It will be readily apparent to a person of ordinary  
30 skill in the art that, with suitable modification,  
31 e.g., interchanging the cage 42 and sleeve 50, the  
32 sleeve may instead be displaced relative to the cage,  
33 to permit fluid communication between the area 24 and  
34 the fluid passage 26. Alternatively, both the cage 42  
35 and sleeve 50 could be displaced relative to the  
36 housing 44 and to each other. No matter the manner in

1 which relative displacement occurs between the cage 42  
2 and sleeve 50, such relative displacement permits  
3 variable choking of fluid flow through the flow ports  
4 60, 62 and sealing engagement between the seal surfaces  
5 54, 56 when desired.

6  
7 The sleeve 50 is preferably closely fitted externally  
8 about the cage 42. Thus, fluid (indicated by arrows  
9 66) from the area 24 flows almost exclusively through  
10 the smaller upper flow ports 60, even though some fluid  
11 may pass between the sleeve 50 and cage 42 to flow  
12 through the larger lower flow ports 62. The fluid 66  
13 may commingle in the fluid passage 26 with fluid 20  
14 from another portion of the well, or, alternatively, if  
15 an injection operation is performed, the fluids may be  
16 oppositely directed and the fluid 66 would then  
17 represent a portion of the injected fluid which passes  
18 outwardly through the openings 46 from the fluid  
19 passage 26.

20  
21 It is a particular benefit of the present invention  
22 that the fluids 20, 66 may be commingled within the  
23 fluid passage 26, and the rate of flow of each may be  
24 accurately regulated utilizing one or more of the  
25 chokes 10 as described hereinabove. For example,  
26 another choke, similar to the illustrated choke 10, may  
27 be installed below the choke 10 to regulate the rate of  
28 flow of the fluid 20, while the choke 10 regulates the  
29 rate of flow of the fluid 66. Alternatively, where the  
30 choke 10 is used in an injection operation, the choke  
31 may be utilized to regulate the rate of fluid flow  
32 outward through the flow ports 60, 62, and, alone or in  
33 combination with additional chokes, may be utilized to  
34 accurately regulate fluid flow rates into multiple  
35 zones in a well. Of course, the choke 10 may also be  
36 useful in single zone completions to regulate fluid

1 flow into or out of the zone.

2

3 Referring additionally now to FIG. 3, an axial portion  
4 of the choke 10 is representatively illustrated in a  
5 fully open configuration in which the cage 42 is  
6 further axially upwardly displaced as compared to that  
7 shown in FIG. 2, completely uncovering both of the flow  
8 port sets 60, 62. The fluid 66 is, thus, permitted to  
9 flow unobstructed inwardly through the flow port sets  
10 60, 62 and into the fluid passage 26. The cage 42 has  
11 been rotated ninety degrees about its longitudinal  
12 axis, so that it may be clearly seen that the ports 62  
13 are now aligned with the openings 46. Therefore,  
14 upward displacement of the cage 42 both uncovers the  
15 ports 62 and aligns the ports with the openings 46 of  
16 the housing 44.

17

18 Preferably, the ports 62 are directly aligned with the  
19 openings 46 in the fully open configuration of the  
20 choke 10 and, furthermore, it is preferred that the  
21 ports 62 and openings 46 are similarly sized in order  
22 to minimize resistance to flow therethrough, reduce  
23 friction losses and minimize erosion of the choke 10.  
24 However, it is to be clearly understood that it is not  
25 necessary in keeping with the principles of the present  
26 invention for the ports 62 to be directly aligned with  
27 the openings 46, nor for the ports 62 to be identical  
28 in size, shape or number with the openings 46. If the  
29 ports 62 are not aligned with the openings 46 in the  
30 fully open configuration of the choke 10, then  
31 preferably a sufficiently large annular space is  
32 provided between the exterior of the cage 42 and the  
33 interior of the housing 44 so that fluid flow  
34 therebetween has minimum resistance.

35

36 Although FIG. 3 representatively illustrates the cage

1 42 rotated so that the ports 62 are directly aligned  
2 with the openings 46, it is to be clearly understood  
3 that such rotation is not necessary in operation of the  
4 choke 10. However, to achieve such direct alignment  
5 between the ports 62 and openings 46, the cage 42  
6 and/or mandrel 30 may be rotationally secured to the  
7 housing 44 in a manner which prevents misalignment  
8 between the ports and openings. For example, a  
9 radially outwardly extending projection or key (not  
10 shown) may be provided on the cage 42 and/or mandrel 30  
11 and cooperatively slidably engaged with a groove or  
12 keyway (not shown) formed internally on the housing 44  
13 and/or actuator 12, sleeve 50, etc., to thereby prevent  
14 relative circumferential displacement between the cage  
15 and housing.

16

17 It will be readily apparent to one of ordinary skill in  
18 the art that the relative proportions of the fluids 20,  
19 66 produced through the tubing string 18 may be  
20 conveniently regulated by selectively permitting  
21 greater or smaller fluid flow rates through the choke  
22 member set 48. With fluid flow substantially  
23 restricted through the ports 60, 62 by the sleeve 50,  
24 the fluid produced through the tubing string 18 may  
25 have a greater proportion of the fluid 20. With fluid  
26 flow being unobstructed through the choke member set  
27 48, the fluid produced through the tubing string 18 may  
28 have a greater proportion of the fluid 66.

29

30 Referring additionally now to FIG. 4, an enlarged axial  
31 portion of the choke 10 is representatively illustrated  
32 with the cage 42 in an intermediate position in which  
33 the lip 52 on the sleeve 50 is overlying the lower flow  
34 ports 62. Thus, fluid flow through the lower flow  
35 ports 62 is restricted by the sleeve 50, and fluid flow  
36 through the upper flow ports 60 is not restricted by

1 the sleeve. It will be readily apparent to a person of  
2 ordinary skill in the art that fluid flow through the  
3 flow ports 62 may be variably choked or restricted by  
4 correspondingly variably displacing the flow ports 62  
5 relative to the sleeve 50. In other words, if the cage  
6 42 is displaced axially upward somewhat from its  
7 position as shown in FIG. 4, fluid flow through the  
8 flow ports 62 will be correspondingly less restricted,  
9 and if the cage is displaced axially downward somewhat,  
10 fluid flow through the flow ports will be  
11 correspondingly more restricted. It will also be  
12 readily apparent that there are an infinite number of  
13 positions of the cage 42 relative to the sleeve 50 in  
14 which fluid flow is permitted through the choke member  
15 set 48.

16

17 The lip 52 is disposed partially obstructing the flow  
18 ports 62. It is believed that the presence of the lip  
19 52 extending outwardly from the sleeve 50 acts to  
20 reduce erosion of the sleeve, particularly the seal  
21 surface 54, and also aids in reducing erosion of the  
22 cage 42 adjacent the flow ports 60, 62 when the fluid  
23 66 is flowing therethrough. The lip 52 deflects the  
24 fluid flow path away from the seal surface 54.

25

26 Additionally, it is believed that the diametrically  
27 opposite orientation of the individual ports of each of  
28 the flow port sets 60, 62 acts to reduce erosion of the  
29 cage 42, in that inwardly directed fluid 66 flowing  
30 through one of two diametrically opposing ports will  
31 interfere with, or impinge on, the fluid flowing  
32 inwardly through the other port, thereby causing the  
33 fluid velocity to decrease and, accordingly, cause the  
34 fluid's kinetic energy to decrease. Thus, the  
35 impinging fluid flows in the center of the cage 42  
36 dissipates the fluid energy onto itself and reduces

1 erosion by containing turbulence and throttling wear  
2 within the cage. The sealing surfaces 54, 56 are  
3 isolated from the flow paths and sealing integrity is  
4 maintained, even though erosion may take place at the  
5 ports 60, 62.

6  
7 Preferably, each of the flow port sets 60, 62 includes  
8 individual ports of equal diameter provided in pairs,  
9 as shown in the accompanying drawings, or greater  
10 numbers, as long as the geometry of the ports is  
11 arranged so that impingement results between fluid  
12 flowing through the ports, and so that such impingement  
13 occurs at or near the center of the cage 42 and away  
14 from the seal surfaces 54, 56, ports, and other flow  
15 controlling elements of the choke 10. As an example of  
16 alternate preferred arrangements of the flow port set  
17 62, three ports of equal size and geometry could be  
18 provided, spaced around the circumference of the cage  
19 42 at 120 degrees apart from each other, or four ports  
20 of equal size and geometry could be provided, spaced  
21 around the circumference of the cage at 90 degrees  
22 apart from each other, etc.

23  
24 It is a particular benefit of the embodiment of the  
25 invention described herein that portions thereof may  
26 erode during normal use, without affecting the ability  
27 of the choke 10 to be closed to fluid flow  
28 therethrough. For example, the lip 52, the flow port  
29 sets 60, 62 and the interior of the cage 42, etc., may  
30 erode without damaging the seal surfaces 54, 56. Thus,  
31 where it is important for safety purposes to ensure the  
32 fluid tight sealing integrity of the wellbore, the  
33 choke 10 preserves its ability to shut off fluid flow  
34 therethrough even where its fluid choking elements have  
35 been degraded.

36

1 Thus has been described the choke 10 and methods of  
2 controlling fluid flow within the well using the choke,  
3 which provide reliability, ruggedness, longevity, and  
4 do not require complex mechanisms. Of course,  
5 modifications, substitutions, additions, deletions,  
6 etc., may be made to the exemplary embodiment described  
7 herein, which changes would be obvious to one of  
8 ordinary skill in the art, and such changes are  
9 contemplated by the principles of the present  
10 invention. For example, the operating mandrel 30 may  
11 be releasably attached to the actuator piston 14, so  
12 that, if the actuator 12 becomes inoperative, the cage  
13 42 may be displaced independently from the piston. As  
14 another example, the cage 42 may be displaced  
15 circumferentially or radially, rather than axially, in  
16 order to selectively open choke member sets positioned  
17 radially about the cage, rather than being positioned  
18 axially relative to the cage. Accordingly, the  
19 foregoing detailed description is to be clearly  
20 understood as being given by way of illustration and  
21 example only, the spirit and scope of the present  
22 invention being limited solely by the appended claims.

23

24 Referring additionally now to FIGS. 5A-5C another choke  
25 70 which embodies principles of the present invention  
26 is representatively illustrated. The choke 70 is  
27 sealingly attached to an actuator 72, a lower portion  
28 of which is shown in FIG. 1A. In a manner which will  
29 be more fully described hereinbelow, the actuator 72 is  
30 used to operate the choke 70. The actuator 72 may be  
31 hydraulically, electrically, mechanically, magnetically  
32 or otherwise controlled without departing from the  
33 principles of the present invention. The  
34 representatively illustrated actuator 72 is the SCRAMS  
35 ICV hydraulically controlled actuator referred to  
36 above. It includes an actuator member or annular

1 piston 74 which is axially displaceable relative to the  
2 choke 70 by appropriate hydraulic pressure applied to  
3 the actuator 72 via control lines (not shown) extending  
4 to the earth's surface.

5  
6 In a method of using the choke 70, the choke and  
7 actuator 72 are positioned within a subterranean well  
8 as part of a production tubing string 78 extending to  
9 the earth's surface. As representatively illustrated  
10 in FIGS. 5A-5C, fluid (indicated by arrows 80) may flow  
11 axially through the choke 70 and actuator 72, and to  
12 the earth's surface via the tubing string 78. The  
13 fluid 80 may, for example, be produced from a zone of  
14 the well below the choke 70. In that case, an  
15 additional portion of the tubing string 78 including a  
16 packer (not shown) may be attached in a conventional  
17 manner to a lower adaptor 82 of the choke 70 and set in  
18 the well in order to isolate the zone below the choke  
19 from other zones of the well, such as a zone in fluid  
20 communication with an area 84 surrounding the choke.

21  
22 In a manner similar to that described hereinabove for  
23 the choke 10, the choke 70 enables accurate regulation  
24 of fluid flow between the external area 84 and an  
25 internal axial fluid passage 86 extending through the  
26 choke. In another method of using the choke 70,  
27 multiple chokes may be installed in the tubing string  
28 18, with each of the chokes corresponding to a  
29 respective one of multiple zones intersected by the  
30 well, and with the zones being isolated from each other  
31 external to the tubing string. Thus, the choke 70 also  
32 enables accurate regulation of a rate of fluid flow  
33 from each of the multiple zones, with the fluids being  
34 commingled in the tubing string 78.

35

36 It is to be understood that, although the tubing string

1 78 is representatively illustrated in the accompanying  
2 drawings with fluid 80 entering the lower adaptor 82  
3 and flowing upwardly through the fluid passage 86, the  
4 lower adaptor 82 may actually be closed off or  
5 otherwise isolated from such fluid flow in a  
6 conventional manner, such as by attaching a bull plug  
7 thereto, or the fluid 80 may be flowed downwardly  
8 through the fluid passage 86, for example, in order to  
9 inject the fluid into a formation intersected by the  
10 well, without departing from the principles of the  
11 present invention. For convenience and clarity of  
12 description, the choke 70 and associated tubing string  
13 78 will be described hereinbelow as it may be used in a  
14 method of producing fluids from multiple zones of the  
15 well, the fluids being commingled within the tubing  
16 string, and it being expressly understood that the  
17 choke 70 may be used in other methods without departing  
18 from the principles of the present invention.

19  
20 An upper portion 76 of the choke 70 is attached to the  
21 actuator 72. The upper portion 76 may be integrally  
22 formed with an outer housing 88 of the actuator 72.  
23 Alternatively, the choke 70 may be threadedly attached  
24 to the actuator 72, or otherwise attached thereto  
25 without departing from the principles of the present  
26 invention. In that manner, the choke 70 may be used  
27 with other actuators, attached directly to the  
28 remainder of the tubing string 78, etc.

29  
30 The piston 74 is attached externally about an upper  
31 generally tubular operating mandrel 90 of the choke 70.  
32 The piston 74 is retained axially between a radially  
33 enlarged external shoulder 92 formed on the mandrel 90  
34 and a ring 94 secured with respect to a circumferential  
35 groove 96 externally formed on the mandrel. In  
36 substantial part, axial displacement of the piston 74

1 by the actuator 72 will cause a corresponding axial  
2 displacement of the mandrel 90. However, in a manner  
3 that will be more fully described below, a portion of  
4 axial displacement of the piston 74 may be utilized in  
5 selectively locking or unlocking the mandrel 90 in its  
6 position with respect to the remainder of the choke 70.

7  
8 The piston 74 is slidingly and sealingly engaged with  
9 the exterior surface of the mandrel 90 and with the  
10 interior surface of the housing 88 of the actuator 72.  
11 In this manner, the piston 74 provides fluid isolation  
12 between two chambers 98, 100 formed radially between  
13 the housing 88 and the mandrel 90. It may be  
14 considered that the mandrel 90 becomes a part of the  
15 actuator 72, since the mandrel in part encloses the  
16 chambers 98, 100 and sealingly engages the piston 74,  
17 but it is to be clearly understood that it is not  
18 necessary, in keeping with the principles of the  
19 present invention, for the mandrel 90 to form a part of  
20 the actuator 72.

21  
22 Axial displacement of the mandrel 90 is accomplished by  
23 applying fluid pressure to one of the chambers 98, 100  
24 to thereby apply an axially directed biasing force to  
25 the piston 74 and, thus, to the mandrel. For example,  
26 if it is desired to displace the mandrel 90 axially  
27 upward to permit fluid flow through the choke 70 or to  
28 decrease resistance to fluid flow therethrough, fluid  
29 pressure may be applied to the lower chamber 100.  
30 Conversely, if it is desired to downwardly displace the  
31 mandrel 90 to prevent fluid flow through the choke 70  
32 or to increase resistance to fluid flow therethrough,  
33 fluid pressure may be applied to the upper chamber 98.

34  
35 To operate the choke 70, the mandrel 90 is axially  
36 displaced relative to the upper portion 76, in order to

1 axially displace an inner axially extending and  
2 generally tubular cage member 102 relative to an outer  
3 housing 104 of the choke. The mandrel 90 is  
4 interconnected to the cage 102 in a manner that permits  
5 a biasing force to be applied to the cage without the  
6 need of applying or maintaining fluid pressure in  
7 either of the actuator's fluid chambers 98, 100. Such  
8 interconnection will be more fully described below.

9  
10 The housing 104 includes a series of axially elongated  
11 and circumferentially spaced apart openings 106, only  
12 one of which is visible in FIG. 1B. The openings 106  
13 are formed through a sidewall portion of the housing  
14 104 and thereby provide fluid communication between the  
15 area 84 external to the choke 70 and the interior of  
16 the housing. The housing 104 is integrally formed with  
17 the upper portion 76 and the lower adaptor 82, with the  
18 openings 106 being positioned axially between the upper  
19 portion and the lower adaptor.

20  
21 A choke member set 108 is disposed within the outer  
22 housing 104 and includes a portion of a sleeve 110  
23 received sealingly within the outer housing. As used  
24 herein, the term "choke member set" is used to describe  
25 an element or combination of elements which perform a  
26 function of regulating fluid flow. In the illustrated  
27 embodiment of the invention, the choke member set 108  
28 includes an upper portion of the sleeve 110 and  
29 portions of the cage 102, which will be more fully  
30 described hereinbelow. The applicants prefer that the  
31 choke member set 108 be configured in some respects  
32 similar to those utilized in the Master Flo Flow Trim  
33 referred to above, although other choke member sets may  
34 be utilized without departing from the principles of  
35 the present invention.

36

1 The sleeve 110 is preferably manufactured of an erosion  
2 resistant material, such as carbide, and is sealingly  
3 received in the housing 104 by shrink fitting it  
4 therein. Of course, other methods of sealingly  
5 attaching the sleeve 110 may be utilized without  
6 departing from the principles of the present invention.  
7 For example, the sleeve 110 could be threaded into the  
8 housing 104, brazed therein, etc.

9  
10 The sleeve 110 includes an axially extending and  
11 internally inclined lip 112 adjacent an externally  
12 inclined seal surface 114. The lip 112 acts to  
13 prevent, or at least greatly reduce, erosion of the  
14 seal surface 114, among other benefits. The seal  
15 surface 114 is cooperatively shaped to sealingly engage  
16 a seal surface 116 internally formed on a seat 118,  
17 which is externally carried on the cage 102 and  
18 integrally formed therewith. In the configuration of  
19 the choke 70 shown in FIG. 5B, the seal surface 114 is  
20 contacting and sealingly engaging the seal surface 116.  
21 Preferably, the seal surfaces 114, 116 are formed of  
22 hardened metal or carbide for erosion resistance,  
23 although other materials, such as resilient materials,  
24 may be utilized without departing from the principles  
25 of the present invention. Additionally, the seat 118,  
26 which includes the seal surface 116, may be wholly or  
27 partially formed of hardened metal or carbide, and may  
28 be separately formed from the cage 102 and sealingly  
29 attached thereto, etc.

30  
31 The cage 102 has a set of comparatively small flow  
32 ports 120, and a set of comparatively larger flow ports  
33 122, formed radially therethrough. The set of ports  
34 120 includes two circumferentially spaced apart and  
35 oppositely disposed ports, although only one is visible  
36 in FIG. 5C, and the set of ports 122 includes four

1 equally circumferentially spaced apart ports, although  
2 only two are visible in FIG. 5C. Of course, other  
3 numbers of ports may be utilized in the flow port sets  
4 120, 122 without departing from the principles of the  
5 present invention. In the configuration of the choke  
6 70 shown in FIG. 5C, the upper ports 120 and lower  
7 ports 122 are radially outwardly overlaid by the sleeve  
8 110, and the seal surfaces 114, 116 are sealingly  
9 engaged. Thus, fluid communication between the  
10 external area 84 and the flow passage 86 through the  
11 flow ports 120, 122 is prevented by the sleeve 110.

12

13 As representatively illustrated in the accompanying  
14 drawings, the flow ports 120 are comparatively small,  
15 in order to provide an initial relatively highly  
16 restricted fluid flow therethrough when the cage 102 is  
17 displaced axially upward to permit fluid flow between  
18 the seal surfaces 114, 116, as more fully described  
19 hereinbelow. However, it is to be understood that the  
20 flow ports 120, 122 may be otherwise dimensioned,  
21 otherwise shaped (e.g., elliptical, oval, square,  
22 oblong, etc.), otherwise positioned, otherwise  
23 dimensioned with respect to each other, and otherwise  
24 positioned with respect to each other, without  
25 departing from the principles of the present invention.  
26 For example, the upper flow ports 120 may actually have  
27 larger or smaller dimensions, may have larger or  
28 smaller dimensions than the lower flow ports 122, may  
29 be positioned differently on the cage 102, and may be  
30 positioned differently with respect to the lower flow  
31 ports. Similar changes may be made to the lower flow  
32 ports 122. Indeed, it is not necessary for the cage  
33 102 to have differently configured sets of flow ports  
34 120, 122 at all. Thus, the flow port sets 120, 122  
35 shown in the accompanying drawings are merely  
36 illustrative and additions, modifications, deletions,

1 substitutions, etc., for example, by making one or more  
2 of the ports oval, elliptical, triangular, or otherwise  
3 shaped, may be made thereto without departing from the  
4 principles of the present invention.

5  
6 As shown in FIGS. 5A-5C, the cage 102 is prevented from  
7 displacing axially downward relative to the sleeve 110  
8 by axial contact between the seal surfaces 114, 116.  
9 Such axial contact may be maintained by maintaining  
10 fluid pressure in the chamber 98 of the actuator 72.  
11 It will be readily apparent to a person of ordinary  
12 skill in the art that such axial contact may also be  
13 maintained by provision of a biasing device 128, which  
14 applies an axially downward biasing force to the cage  
15 102. Operation of the biasing device 128 in  
16 maintaining axial contact between the seal surfaces  
17 114, 116 will be more fully described hereinbelow.

18  
19 For displacement of the mandrel 90 and cage 102 in the  
20 event of a failure of the actuator 72, conventional  
21 shifting profiles 124 are internally formed on the  
22 mandrel 90 and a mandrel extension 130 threadedly  
23 attached to a lower end of the mandrel. Either of the  
24 shifting profiles 124 may be engaged by a shifting tool  
25 (not shown) conveyed on wireline, slickline, coiled  
26 tubing, etc., in a conventional manner. Of course,  
27 other profiles and methods of displacing the mandrel 90  
28 and/or cage 102 may be utilized without departing from  
29 the principles of the present invention. Additionally,  
30 other methods of maintaining the cage 102 in a desired  
31 position relative to the housing 104 and/or sleeve 110  
32 may be utilized without departing from the principles  
33 of the present invention. For example, detents, etc.,  
34 may be configured to cooperatively engage the cage 102  
35 and/or housing 104. For this purpose, a locking  
36 mechanism 132 is provided in the choke 70, and will be

1 more fully described below.

2

3 If the cage 102 is displaced axially upward relative to  
4 the sleeve 110 and housing 104, the seal surfaces 114,  
5 116 will disengage and fluid flow will be permitted  
6 between the external area 84 and the fluid passage 86.  
7 Thus, the choke member set 108 is selectively openable  
8 by axially displacing the cage 102 upward from its  
9 position shown in FIG. 5C. The choke member set 108  
10 may be maintained in an open position by, for example,  
11 a suitable latching device (not shown).

12

13 It will be readily apparent to a person of ordinary  
14 skill in the art that, with suitable modification,  
15 e.g., interchanging the cage 102 and sleeve 110, the  
16 sleeve may instead be displaced relative to the cage,  
17 to permit fluid communication between the area 84 and  
18 the fluid passage 86. Alternatively, both the cage 102  
19 and sleeve 110 could be displaced relative to the  
20 housing 104 and to each other. No matter the manner in  
21 which relative displacement occurs between the cage 102  
22 and sleeve 110, such relative displacement permits  
23 variable choking of fluid flow through the flow ports  
24 120, 122 and sealing engagement between the seal  
25 surfaces 114, 116 when desired in a manner similar to  
26 that described above for the choke 10.

27

28 Preferably, the ports 120,122 are directly aligned with  
29 the openings 106 in the fully open configuration of the  
30 choke 70 and, furthermore, it is preferred that the  
31 combined ports 120,122 and openings 106 are similarly  
32 sized in order to minimize resistance to flow  
33 therethrough, reduce friction losses and minimize  
34 erosion of the choke 70. Referring additionally now to  
35 FIG. 6, an elevational view of one of the openings 106  
36 is representatively illustrated. The opening 106 shown

1 in FIG. 6 has a generally axially extending upper  
2 portion 134 and a generally circular shaped lower  
3 portion 136. When the choke member set 108 is in its  
4 fully open position, the comparatively small flow ports  
5 120 are positioned radially opposite the comparatively  
6 small upper portions 134 of the openings 106, and the  
7 comparatively large flow ports 122 are positioned  
8 radially opposite the comparatively large lower  
9 portions 136 of the openings. In this manner, the  
10 openings 106 are conformed in relation to the  
11 dimensions and orientations of the flow port sets 120,  
12 122 to aid in minimizing erosion of various elements of  
13 the choke 70.

14

15 However, it is to be clearly understood that it is not  
16 necessary in keeping with the principles of the present  
17 invention for the ports 120, 122 to be directly aligned  
18 with the openings 106, nor for the ports 120, 122 to be  
19 identical in size, shape or number with the openings  
20 106. If the ports 120, 122 are not aligned with the  
21 openings 106 in the fully open configuration of the  
22 choke 70, then preferably a sufficiently large annular  
23 space is provided between the exterior of the cage 102  
24 and the interior of the housing 104 so that fluid flow  
25 therebetween has minimum resistance.

26

27 In order to achieve such alignment between the ports  
28 120, 122 and openings 106 in the representatively  
29 illustrated choke 70, the cage 102 is rotationally  
30 secured to the housing 104 in a manner which prevents  
31 misalignment between the ports and openings.  
32 Specifically, an alignment key 138 extends radially  
33 through, and is fastened to, the outer housing 104 and  
34 axially slidingly engages a slotted recess 140 formed  
35 externally on a generally tubular cage extension 142  
36 attached to the cage 102 and extending axially upward

1 therefrom. The cage extension 142 is sealingly attached  
2 to the cage 102 by shrink fitting it thereto, although  
3 any other suitable connection method, such as brazing,  
4 threading, integrally forming, etc., may be utilized  
5 without departing from the principles of the present  
6 invention. The applicants use shrink fitting since, in  
7 the representatively illustrated embodiment of the  
8 invention, the cage 102 is made of a highly erosion  
9 resistant material, such as carbide, while the cage  
10 extension 142 is made of an alloy steel, although other  
11 materials may be used. Thus, engagement of the key 138  
12 with the slotted recess 140 prevents circumferential  
13 displacement of the cage 102 relative to the housing  
14 104, but permits axial displacement of the cage  
15 relative to the housing.

16

17 The cage 102 is attached to the mandrel 90 in a manner  
18 that permits the biasing device 128 to exert a biasing  
19 force on the cage, so that the sealing surfaces 114,  
20 116 remain sealingly engaged when the choke member set  
21 108 is in its closed position as shown in FIG. 5C. The  
22 biasing device 128 is representatively illustrated as a  
23 stack of Belleville springs, although other biasing  
24 devices, such as coil springs, resilient members, etc.,  
25 may be utilized without departing from the principles  
26 of the present invention. The biasing device 128 is  
27 axially retained between an upper ring 144 and a lower  
28 ring 146, which are slidably disposed on a radially  
29 reduced lower portion 148 formed externally on the  
30 mandrel 90. The lower ring 146 is threadedly attached  
31 to the cage extension 142. Thus, axially downward  
32 displacement of the mandrel 90 after the sealing  
33 surfaces 114, 116 have contacted, will cause the  
34 biasing device 128 to be compressed axially between the  
35 rings 144, 146, and will apply a downwardly directed  
36 biasing force to the cage 102 via the cage extension

1 142.

2

3 A seal or packing stack 150 provides sealing engagement  
4 radially between the mandrel 90 and the cage extension  
5 142, while permitting relative axial displacement  
6 therebetween. The seal 150 is axially retained between  
7 an expandable ring 152 installed in an annular groove  
8 formed on the radially reduced portion 148, and the  
9 mandrel extension 124.

10

11 The locking mechanism 132 permits the mandrel 90 to be  
12 releasably secured in its axial position relative to  
13 the housing 104, after the mandrel has been axially  
14 downwardly displaced so that the sealing surfaces 114,  
15 116 contact, and after the mandrel has been further  
16 downwardly displaced so that the biasing device 128  
17 exerts a downwardly biasing force on the cage 102 as  
18 described above and shown in FIG. 5C. In this manner,  
19 the biasing force will be maintained, even though fluid  
20 pressure in the upper chamber 98 of the actuator 72 may  
21 be intentionally relieved or accidentally lost.

22

23 The locking mechanism 132 includes a radially  
24 expandable ring 154, which is radially outwardly  
25 retained by a radially reduced lower portion 156 formed  
26 on the piston 74. The piston 74 is biased downwardly,  
27 so that the lower portion 156 radially outwardly  
28 extends the ring 154, by a biasing device 158, which is  
29 representatively illustrated as a stack of Belleville  
30 springs. The biasing device 158 is axially retained  
31 between the ring 94 and the piston 74.

32

33 When radially outwardly extended as shown in FIG. 5B,  
34 the ring 154 engages a radially enlarged groove 160  
35 formed internally on the actuator housing 88 and abuts  
36 the shoulder 92 on the mandrel 90. Such engagement

1 between the ring 154 and the groove 160 prevents  
2 axially upward displacement of the mandrel 90 relative  
3 to the housing 104. Thus, with the mandrel 90 in its  
4 position as shown in FIGS. 5A-5C, the biasing device  
5 128 is biasing the sealing surfaces 114, 116 toward  
6 sealing engagement with each other, the biasing device  
7 158 is biasing the piston 74 to extend the ring 154  
8 into engagement with the groove 160, and the mandrel 90  
9 is prevented from displacing axially upward.

10

11 To radially inwardly retract the ring 154 and thereby  
12 disengage the ring from the groove 160, fluid pressure  
13 may be applied to the lower chamber 100, which is in  
14 fluid communication with the piston 74, and which will  
15 bias the piston upwardly against the biasing force  
16 exerted by the biasing device 158. When sufficient  
17 fluid pressure has been applied to the chamber 100 to  
18 overcome the biasing force exerted by the biasing  
19 device 158, the piston 74 will displace upwardly,  
20 thereby permitting the ring 154 to radially inwardly  
21 retract out of engagement with the groove 160. Such  
22 fluid pressure will also bias the mandrel 90 upwardly,  
23 causing the mandrel to displace upwardly, eventually  
24 removing the biasing force exerted by the biasing  
25 device 128 from the cage 102.

26

27 When it is again desired to lock the mandrel 90 in its  
28 position relative to the housing 104, fluid pressure  
29 may be relieved from the lower chamber 100 and applied  
30 to the upper chamber 98 to thereby bias the mandrel  
31 downwardly. When the ring 154 is radially opposite the  
32 groove 160, the biasing force exerted by the biasing  
33 device 158, in addition to the biasing force resulting  
34 from any fluid pressure in the upper chamber 98, will  
35 cause the lower portion 156 of the piston to radially  
36 outwardly extend the ring into engagement with the

1 groove 160. Of course, it will be readily apparent to  
2 one of ordinary skill in the art that the biasing  
3 device 158 continually exerts a downwardly biasing  
4 force on the piston 74, while fluid pressures in the  
5 chambers 98, 100 only exert biasing forces on the  
6 piston when those fluid pressures are applied to the  
7 chambers. Thus, an operator may apply fluid pressure  
8 to the upper chamber 98 to close the choke member set  
9 108 and to apply a biasing force to the choke member  
10 set so that the sealing surfaces 114, 116 remain  
11 sealingly engaged, and then relieve the fluid pressure  
12 from the upper chamber while the mandrel remains locked  
13 in its position relative to the housing. Thereafter,  
14 when it is desired to open the choke member set 108,  
15 the operator may apply fluid pressure to the lower  
16 chamber 100 to permit relative displacement between the  
17 mandrel 90 and the housing 104.

18  
19 Thus has been described the choke 70 and methods of  
20 controlling fluid flow within the well using the choke,  
21 which provide reliability, ruggedness, longevity, and  
22 do not require complex mechanisms. Of course,  
23 modifications, substitutions, additions, deletions,  
24 etc., may be made to the exemplary embodiment described  
25 herein, which changes would be obvious to one of  
26 ordinary skill in the art, and such changes are  
27 contemplated by the principles of the present  
28 invention. For example, the operating mandrel 90 may  
29 be releasably attached to the actuator piston 74, so  
30 that, if the actuator 72 becomes inoperative, the cage  
31 102 may be displaced independently from the piston. As  
32 another example, the cage 102 may be displaced  
33 circumferentially or radially, rather than axially, in  
34 order to selectively open choke member sets positioned  
35 radially about the cage, rather than being positioned  
36 axially relative to the cage. As a further example, a

1 series of lugs, keys or collets may be utilized in  
2 place of the expandable ring 154 in the locking  
3 mechanism 132. Accordingly, the foregoing detailed  
4 description is to be clearly understood as being given  
5 by way of illustration and example only, the spirit and  
6 scope of the present invention being limited solely by  
7 the appended claims.

8  
9 The features of the dependent claims 2 to 37, 39 to 42,  
10 44 to 47, 49 to 53, 55 to 58 or 60 to 62 can be  
11 combined with the invention as defined in any one of  
12 claims 1, 38, 43, 48, 54 or 59.

13  
14

1     CLAIMS

2

3     1.    Apparatus operatively positionable within a  
4     subterranean well, the apparatus comprising:  
5         a first member; and  
6         a second member having a port for flow of fluid,  
7     fluid flow through the port being regulatable by  
8     displacement of the first member relative to the second  
9     member.

10

11    2.    Apparatus according to Claim 1, wherein the first  
12    and second members are sealingly engageable to prevent  
13    fluid flow through the port.

14

15    3.    Apparatus according to Claim 2, further comprising  
16    a biasing device, the biasing device applying a biasing  
17    force to one of the first and second members to thereby  
18    maintain sealing engagement of the one of the first and  
19    second members with the other of the first and second  
20    members.

21

22    4.    Apparatus according to any preceding Claim,  
23    further comprising a locking mechanism, the locking  
24    mechanism selectively preventing displacement of the  
25    first member relative to the second member.

26

27    5.    Apparatus according to Claim 4, wherein the  
28    locking mechanism is configured to selectively permit  
29    displacement of the first member relative to the second  
30    member upon application of fluid pressure to the  
31    locking mechanism.

32

33    6.    Apparatus according to either of Claims 4 or 5,  
34    wherein the first member is sealingly engageable with  
35    the second member, and wherein the locking mechanism is  
36    configured to releasably prevent displacement of the

1 first member relative to the second member when the  
2 first member is sealingly engaged with the second  
3 member.

4  
5 7. Apparatus according to any preceding Claim,  
6 further comprising a generally tubular outer housing,  
7 the first and second members being disposed at least  
8 partially within the outer housing, and the outer  
9 housing being configured for co-operative attachment to  
10 a tubing string positioned within the subterranean  
11 well.

12  
13 8. Apparatus according to any preceding Claim,  
14 wherein the first and second members are generally  
15 tubular and the second member is slidingly disposed  
16 relative to the first member.

17  
18 9. Apparatus according to any preceding Claim,  
19 wherein the second member has at least one flow port  
20 formed through a sidewall portion thereof.

21  
22 10. Apparatus according to any preceding Claim,  
23 wherein the second member is variably positionable  
24 relative to the first member to variably regulate fluid  
25 flow through the flow port.

26  
27 11. Apparatus according to any preceding Claim,  
28 wherein the second member is secured to a mandrel, the  
29 mandrel being displaceable relative to the first member  
30 to thereby displace the second member relative to the  
31 first member.

32  
33 12. Apparatus according to Claim 11, wherein the  
34 mandrel is rotatably secured to the second member.

35  
36 13. Apparatus according to either of Claims 11 or 12,

1 wherein the mandrel is configured for displacement  
2 relative to the first member by application of fluid  
3 pressure thereto.

4

5 14. Apparatus according to any of Claims 11 to 13,  
6 wherein the mandrel has a shifting profile formed  
7 thereon, and wherein the profile is configured for  
8 engagement with a shifting tool.

9

10 15. Apparatus according to any of Claims 3 to 14,  
11 wherein the biasing device is configured to bias the  
12 second member toward sealing engagement with the first  
13 member.

14

15 16. Apparatus according to any preceding Claim,  
16 wherein the second member is selectively and releasably  
17 securable relative to the first member.

18

19 17. Apparatus according to any of Claims 2 to 16,  
20 wherein the second member is securable relative to the  
21 first member when the second member sealingly engages  
22 the first member to prevent fluid flow through the flow  
23 port.

24

25 18. Apparatus according to any preceding Claim,  
26 wherein the first member is a sleeve, and wherein the  
27 second member is a cage.

28

29 19. Apparatus according to any preceding Claim,  
30 wherein the second member comprises a generally tubular  
31 member having a flow passage extending generally  
32 axially therethrough and the first member comprising a  
33 sleeve slidingly disposed relative to the second  
34 member.

35

36 20. Apparatus according to any preceding Claim,

1 wherein the second member is positionable relative to  
2 the first member in a selected one of a first position  
3 in which the first member substantially prevents fluid  
4 flow through the port, a second position in which  
5 substantially unobstructed fluid flow is permitted  
6 through the port, and a third position in which fluid  
7 flow through the port is partially obstructed by the  
8 first member.

9

10 21. Apparatus according to Claim 20, wherein the first  
11 member has a lip extending outwardly therefrom, the lip  
12 being disposed generally radially opposite the port  
13 when the second member is in the third position.

14

15 22. Apparatus according to Claim 21, wherein the lip  
16 is configured to inhibit erosion of the first member  
17 when the second member is in the third position.

18

19 23. Apparatus according to either of Claims 21 or 22,  
20 wherein the lip is configured to inhibit erosion of the  
21 second member when the second member is in the third  
22 position.

23

24 24. Apparatus according to any of Claims 20 to 23,  
25 further comprising a first seal surface carried on the  
26 second member, and a second seal surface formed on the  
27 first member, the first and second seal surfaces being  
28 sealingly engaged when the second member is in the  
29 first position.

30

31 25. Apparatus according to any preceding Claim,  
32 further comprising a generally tubular outer housing,  
33 the first and second members being disposed at least  
34 partially within the housing.

35

36 26. Apparatus according to Claim 25, wherein the first

1 member is coaxially attached within the housing.

2

3 27. Apparatus according to either of Claims 25 or 26,  
4 wherein an end portion of the first member has a lip  
5 extending outwardly therefrom, and wherein the lip is  
6 positioned radially inward relative to an opening  
7 formed through a sidewall portion of the housing.

8

9 28. Apparatus according to any of Claims 9 to 27,  
10 wherein the second member further has a second port  
11 formed through the second member sidewall portion, the  
12 first and second ports being axially spaced apart.

13

14 29. Apparatus according to Claim 28 when dependent  
15 upon any of Claims 20 to 24 or 26 or 27, and to Claim  
16 28 when dependent upon Claim 25 when dependent upon any  
17 of Claims 20 to 24, wherein in the first, second and  
18 third positions of the second member, fluid flow is  
19 permitted through the second port.

20

21 30. Apparatus according to Claim 29 or to Claim 28  
22 when dependent upon any of Claims 20 to 24 or 26 or 27,  
23 and to Claim 28 when dependent upon Claim 25 when  
24 dependent upon any of Claims 20 to 24, wherein the  
25 second member further has fourth and fifth positions  
26 relative to the first member, fluid flow being  
27 substantially permitted through the second port when  
28 the second member is in the fourth position, and fluid  
29 flow through the second port being substantially  
30 prevented when the second member is in the fifth  
31 position.

32

33 31. Apparatus according to any of Claims 28 to 30,  
34 wherein the second port has a flow area unequal to a  
35 flow area of the first port.

36

1 32. Apparatus according to any of Claims 9 to 27,  
2 wherein the second member further has a second port  
3 formed through the sidewall portion thereof, and  
4 wherein the second port is positioned opposite the  
5 first port, whereby when fluid flows inwardly through  
6 each of the first and second ports, the fluid flows  
7 interfere with each other and inhibit erosion of the  
8 second member.

9  
10 33. Apparatus according to any of Claims 20 to 32,  
11 wherein the second member is further positionable in an  
12 infinite number of positions between the first and  
13 second positions.

14  
15 34. Apparatus according to any preceding Claim,  
16 wherein the first member is radially outwardly disposed  
17 about the second member.

18  
19 35. Apparatus according to Claim 34, further  
20 comprising a generally tubular seat carried externally  
21 on the second member, the seat sealingly engaging the  
22 first member when the second member is in the first  
23 position.

24  
25 36. Apparatus according to any preceding Claim,  
26 wherein the apparatus is a flow control apparatus.

27  
28 37. Apparatus according to any preceding Claim,  
29 wherein the apparatus comprises a choke.

30  
31 38. A choke operatively positionable within a  
32 subterranean well and operatively connectable to an  
33 actuator disposed within the well, the actuator having  
34 an actuator member which is displaceable relative to  
35 the remainder of the actuator in a selected one of  
36 first and second opposite directions, the choke

1 comprising:

2 a first member interconnectable to the actuator  
3 member and displaceable therewith;

4 a seal surface carried on the first member; and

5 a second member slidably disposed relative to the  
6 first member,

7 the first member being displaceable in the first  
8 direction by the actuator member to sealingly engage  
9 the second member with the seal surface to thereby  
10 substantially prevent fluid flow through a sidewall  
11 portion of the first member, and the first member being  
12 displaceable in the second direction by the actuator  
13 member to thereby substantially permit fluid flow  
14 through the sidewall portion of the first member.

15

16 39. The choke according to Claim 38, wherein the  
17 second member is a sleeve externally disposed about the  
18 first member.

19

20 40. The choke according to either of Claims 38 or 39,  
21 further comprising a port formed through the sidewall  
22 portion, the port being positionable between the seal  
23 surface and the second member when the first member is  
24 displaced in the second direction.

25

26 41. The choke according to Claim 40, wherein the first  
27 member is variably positionable relative to the second  
28 member so that fluid flow through the port is  
29 correspondingly variably restricted.

30

31 42. The choke according to either of Claims 40 or 41,  
32 wherein the sleeve has a flow deflection lip formed  
33 thereon, and wherein the lip is positionable in an  
34 overlying relationship to the port.

35

36 43. A choke operatively positionable within a

1 subterranean well, the choke comprising:

2 a generally tubular inner cage having a port  
3 formed through a sidewall portion thereof;

4 a seat carried externally on the cage spaced apart  
5 from the port; and

6 a sleeve externally slidably disposed on the  
7 cage.

8

9 44. The choke according to Claim 43, wherein the  
10 sleeve has opposite ends, one of the sleeve opposite  
11 ends being configured for sealing engagement with the  
12 seat.

13

14 45. The choke according to Claim 44, wherein the other  
15 of the sleeve opposite ends is sealingly received  
16 within an outer housing.

17

18 46. The choke according to Claim 45, wherein the  
19 sleeve is rigidly attached to the housing, the one of  
20 the sleeve opposite ends being positioned radially  
21 opposite an opening formed through a sidewall portion  
22 of the housing.

23

24 47. The choke according to any of Claims 43 to 46,  
25 wherein the seat and sidewall portion of the cage are  
26 formed of a material having an erosion resistance  
27 greater than that of the remainder of the cage.

28

29 48. A method of controlling fluid flow into a tubing  
30 string disposed within a subterranean well, the method  
31 comprising the steps of:

32 attaching an actuator to the tubing string;

33 operatively attaching a choke to the actuator, the  
34 choke being capable of regulating fluid flow through a  
35 sidewall portion thereof, the choke including a choke  
36 member set; and

1           actuating the actuator to variably open the choke  
2 member set and thereby variably choke fluid flow  
3 therethrough.

4

5           49. The method according to Claim 48, wherein the step  
6 of actuating the actuator to open the choke member set  
7 further comprises displacing a first tubular member  
8 relative to a second tubular member.

9

10          50. The method according to Claim 49, wherein the  
11 first tubular member displacing step comprises  
12 displacing a seat portion of the choke member set out  
13 of sealing engagement with a sleeve portion of the  
14 choke member set.

15

16          51. The method according to Claim 50, wherein the  
17 first tubular member displacing step further comprises  
18 displacing a port formed through the first tubular  
19 member relative to the choke member set sleeve portion.

20

21          52. The method according to Claim 51, wherein the port  
22 displacing step comprises displacing the port from a  
23 first position in which the port is radially inwardly  
24 disposed relative to the sleeve portion, to a second  
25 position in which the port is at least partially open  
26 to fluid flow therethrough.

27

28          53. The method according to either of Claims 51 or 52,  
29 wherein the port displacing step comprises displacing  
30 the port from a first position in which fluid flow  
31 through the port is prevented by sealing engagement of  
32 the sleeve portion with the seat portion, to a second  
33 position in which fluid flow through the port is  
34 partially obstructed by the sleeve portion.

35

36          54. A method of controlling fluid flow within a

1 subterranean well, comprising the steps of:

2 providing an actuator having an actuator member  
3 which is displaceable relative to the remainder of the  
4 actuator in a selected one of first and second opposite  
5 directions;

6 providing a choke including a first member  
7 interconnectable to the actuator member and  
8 displaceable therewith, a seal surface carried on the  
9 first member, and a second member slidably disposed  
10 relative to the first member, the first member  
11 displacing relative to the second member and thereby  
12 permitting a progressively greater rate of fluid flow  
13 through a sidewall portion of the first member when the  
14 actuator member is displaced in the first direction,  
15 and the first member displacing relative to the second  
16 member and thereby increasingly restricting fluid flow  
17 through the sidewall portion when the actuator member  
18 is displaced in the second direction;

19 operatively interconnecting the actuator to the  
20 choke; and

21 positioning the actuator and choke within the  
22 well.

23

24 55. The method according to Claim 54, further  
25 comprising the step of displacing the actuator member  
26 in the second direction to sealingly engage the second  
27 member and the seal surface and thereby prevent fluid  
28 flow through the sidewall portion.

29

30 56. The method according to either of Claims 54 or 55,  
31 wherein the choke is provided further including first  
32 and second ports formed through the sidewall portion.

33

34 57. The method according to Claim 56, wherein the  
35 choke is provided with the first port having a  
36 restriction to fluid flow therethrough which is not

1 equal to a restriction to fluid flow through the second  
2 port.

3

4 58. The method according to any of Claims 54 to 57,  
5 further comprising the step of displacing the actuator  
6 member in the first direction, thereby telescopingly  
7 extending the first member from within the second  
8 member.

9

10 59. A method of controlling fluid flow within a  
11 subterranean well, comprising the steps of:

12 providing a tubular member having a plurality of  
13 spaced apart ports formed therethrough;

14 providing a blocking member for blocking fluid  
15 flow through the plurality of ports;

16 positioning the tubular member and blocking member  
17 within the well; and

18 displacing the tubular member relative to the  
19 blocking member to thereby permit fluid flow through  
20 the plurality of ports.

21

22 60. The method according to Claim 59, further  
23 comprising the step of providing a housing, the  
24 blocking member being disposed within, and attached to,  
25 the housing, and wherein the step of displacing the  
26 tubular member further comprises displacing the tubular  
27 member relative to the housing to thereby permit fluid  
28 flow through a sidewall portion of the housing.

29

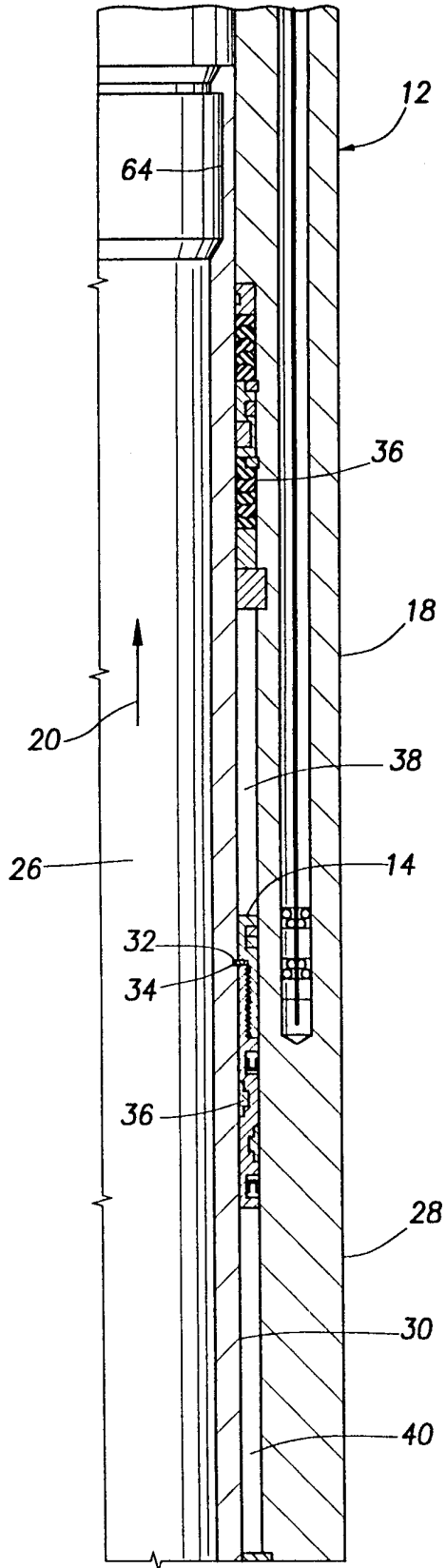
30 61. The method according to either of Claims 59 or 60,  
31 wherein the tubular member displacing step further  
32 comprises selecting a first one of the ports for fluid  
33 flow therethrough by displacing the tubular member in a  
34 first selected direction.

35

36 62. The method according to Claim 61, wherein the

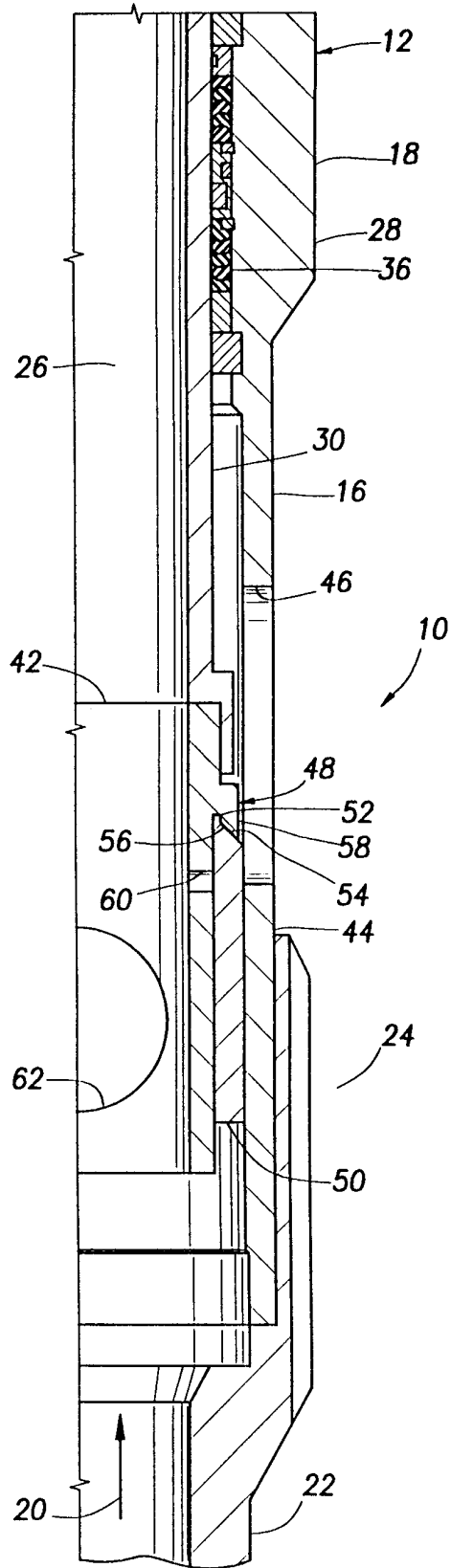
1 tubular member displacing step further comprises  
2 selecting a second one of the ports for fluid flow  
3 therethrough, in addition to the first one of the  
4 ports, by further displacing the tubular member in the  
5 first selected direction.

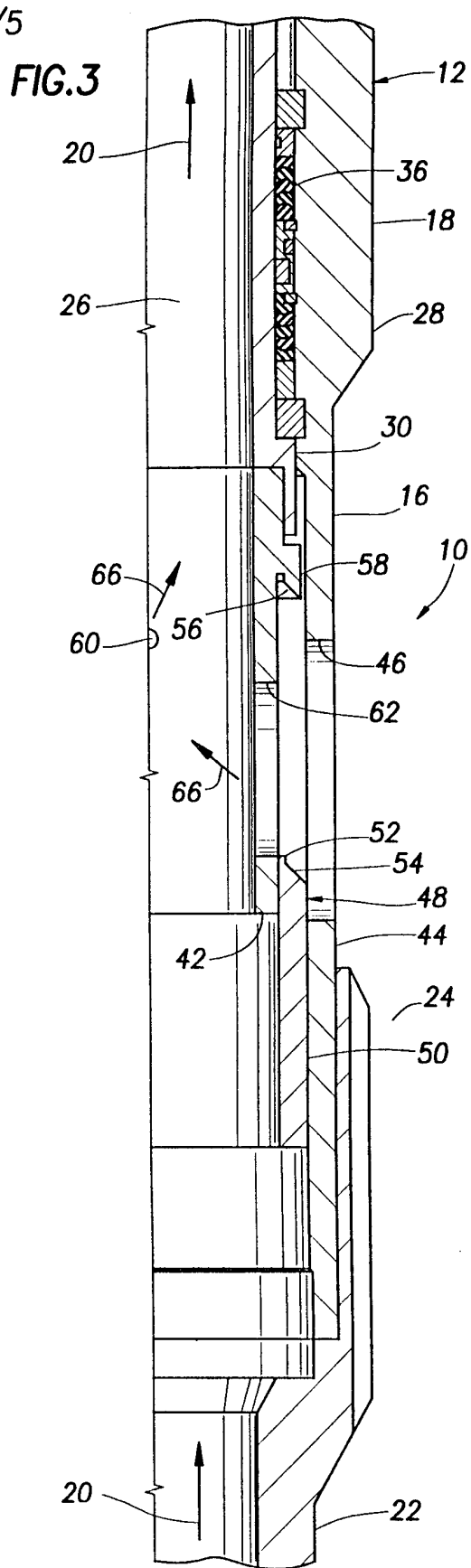
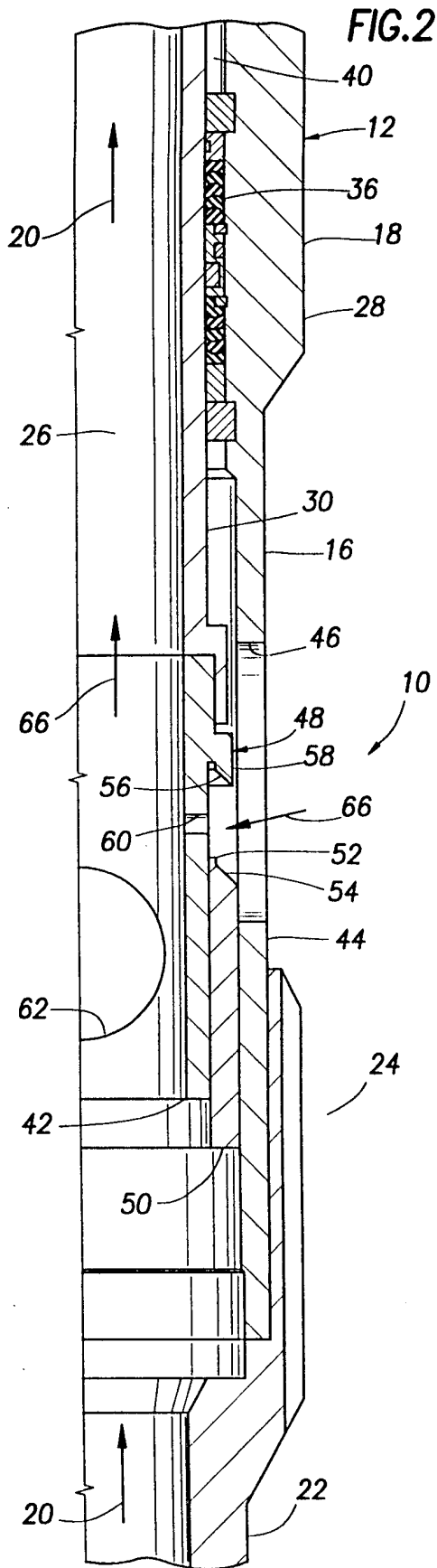
FIG. 1A



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FIG. 1B





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FIG. 4

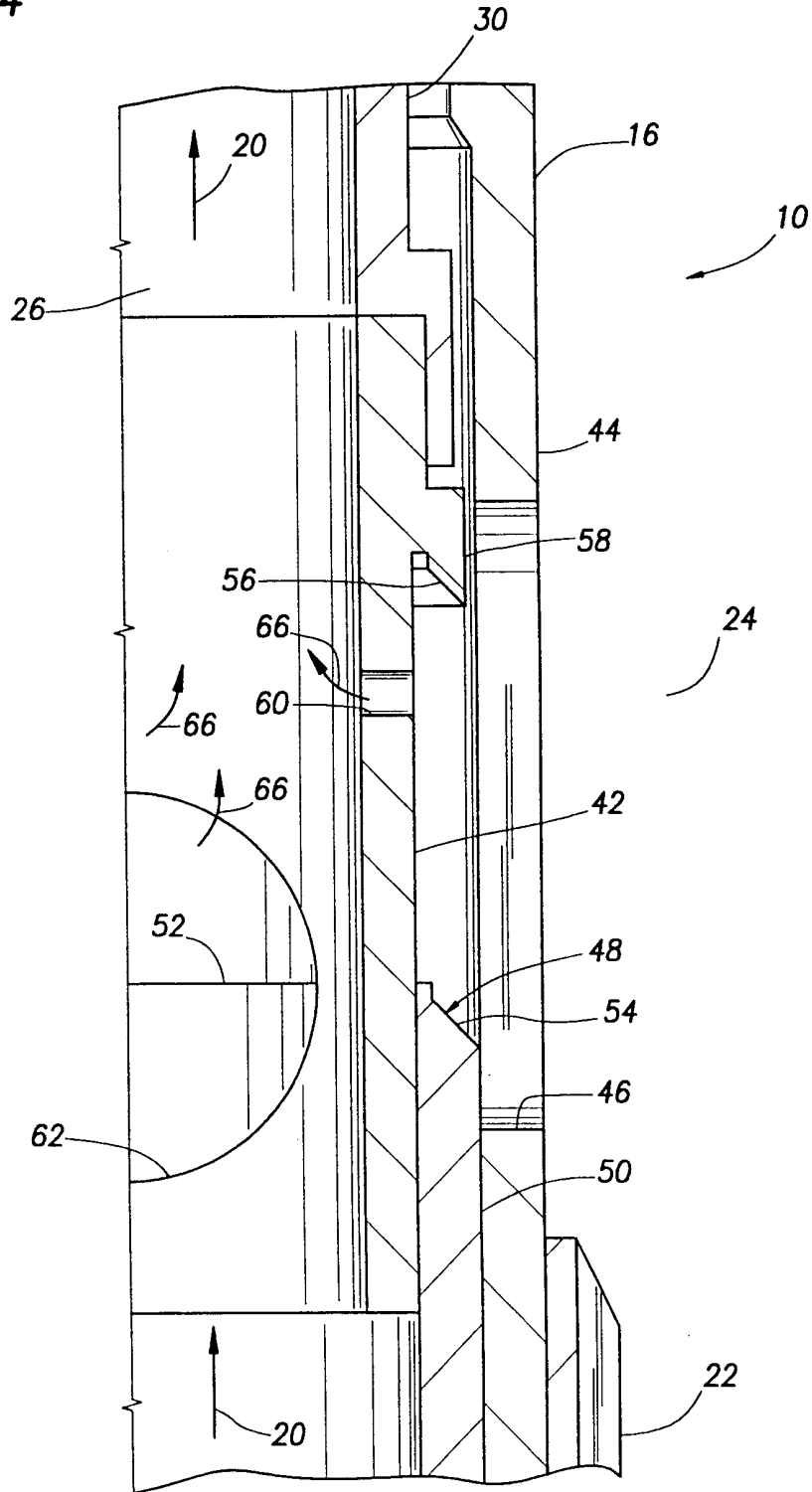
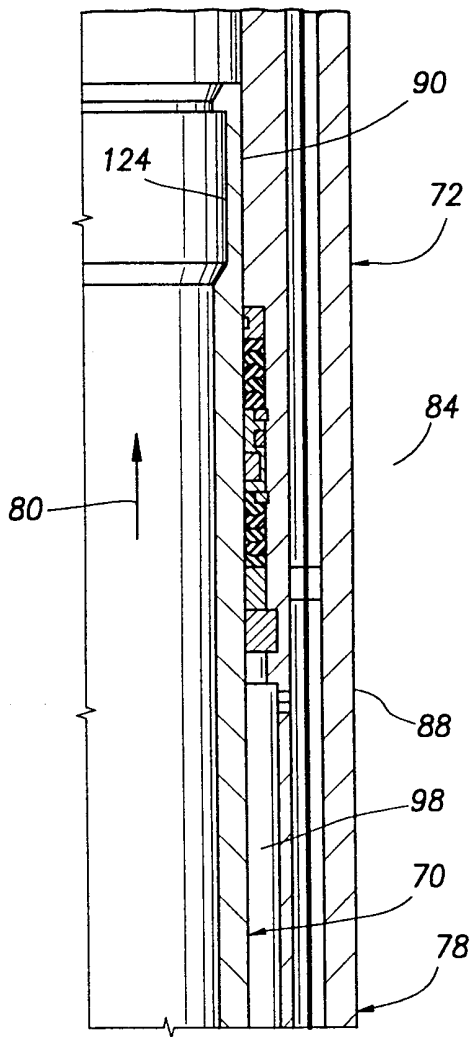


FIG.5A



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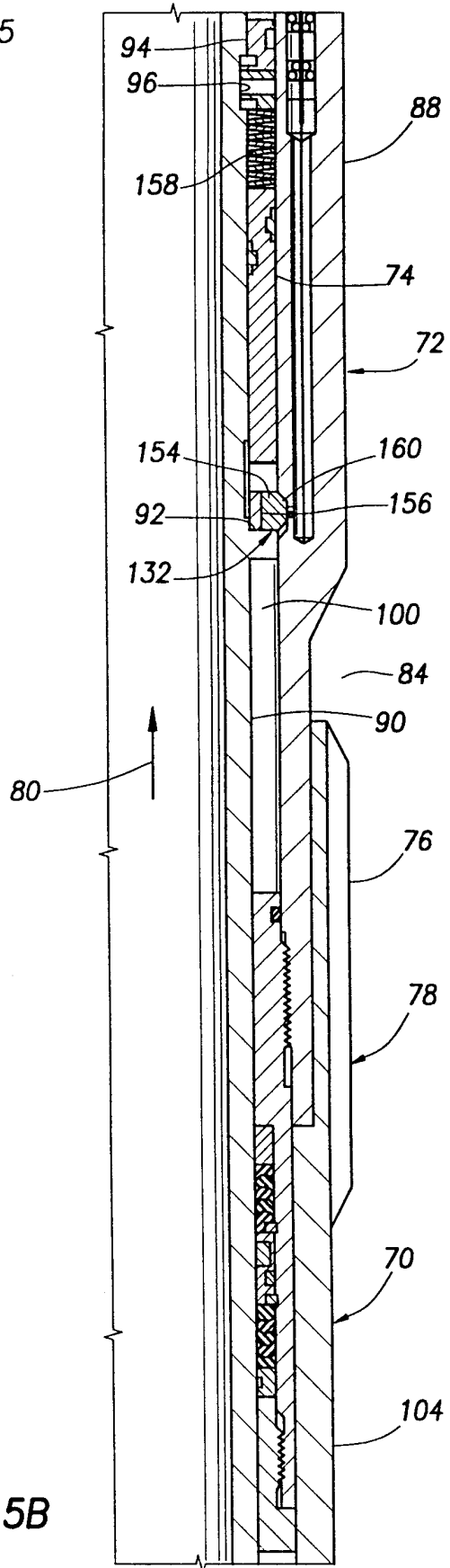


FIG.5B

FIG.5C 5/5

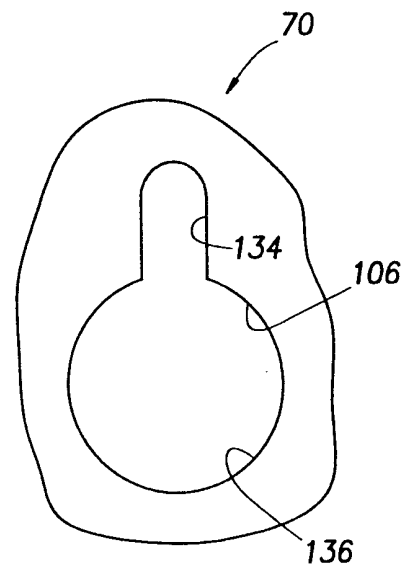
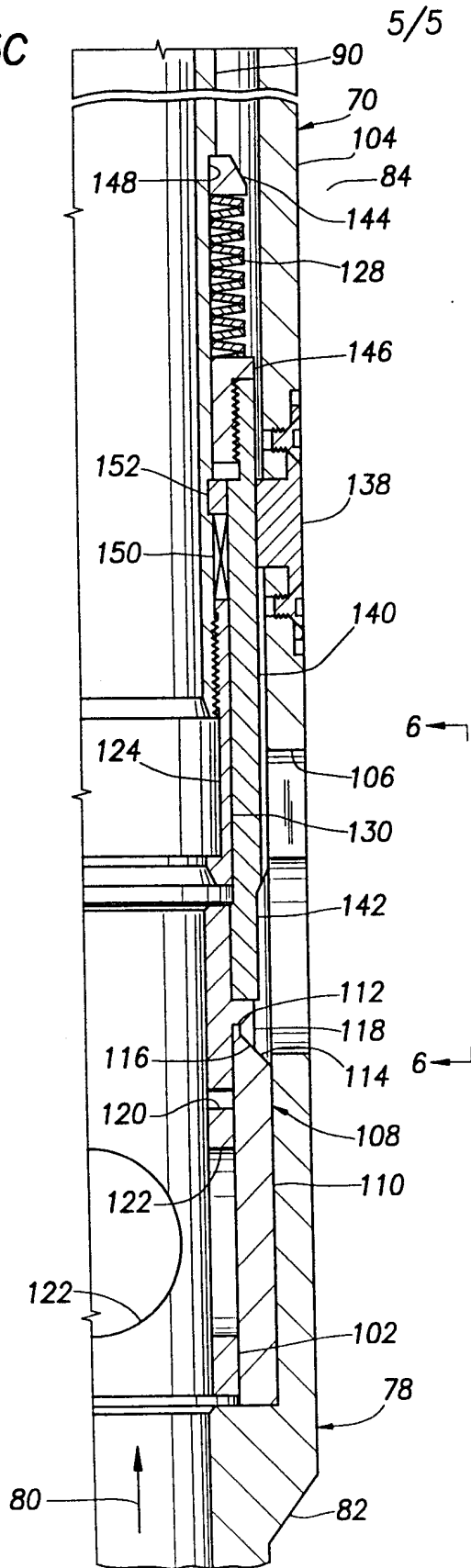


FIG.6