Jan. 20, 1959 R. O. CHAMBERLAIN ET AL 2,869,645

APPARATUS FOR CONTROLLING THE FLOW OF FLUIDS IN A MULTI-STRATA WELL

Filed Dec. 8, 1954 2 Sheets-Sheet 1

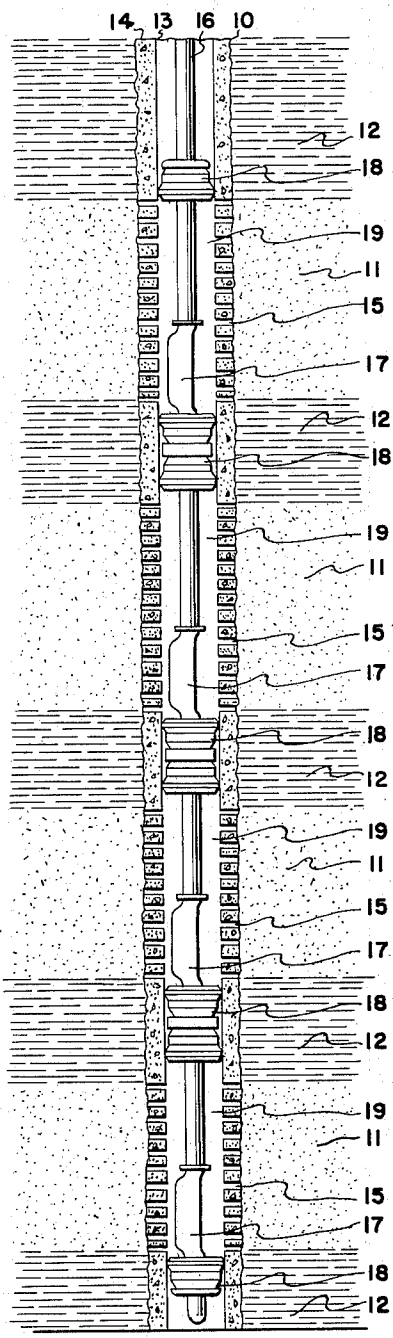
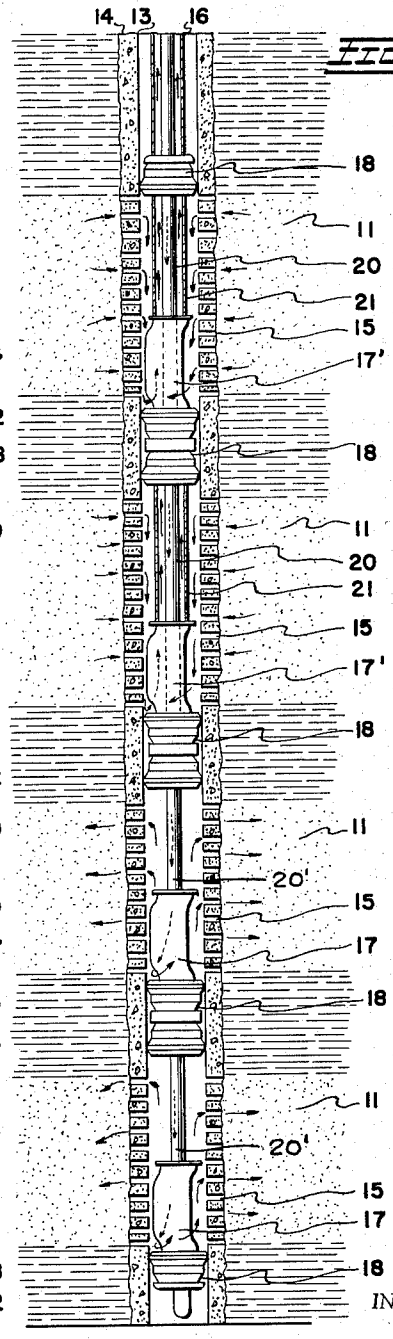


Fig. 1.

Fig. 2.



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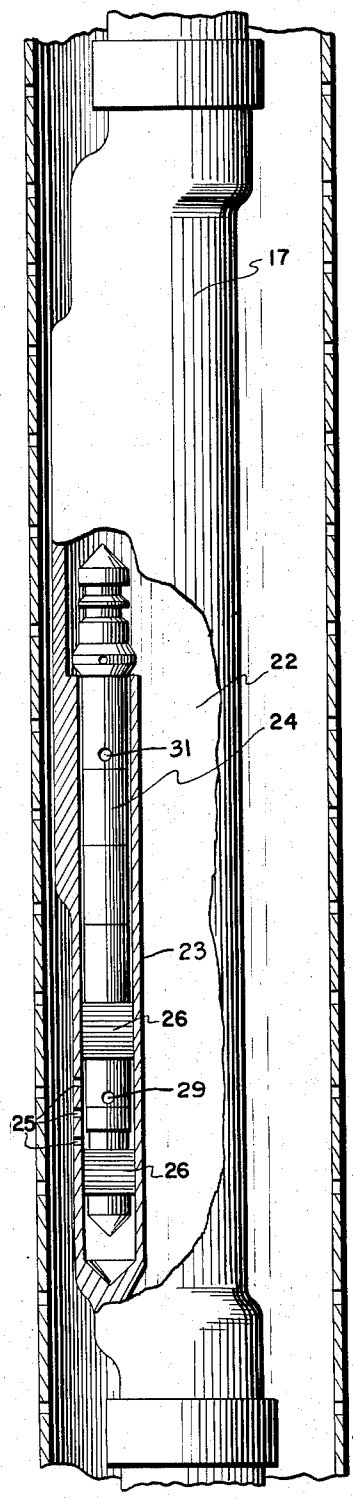


Fig. 3.

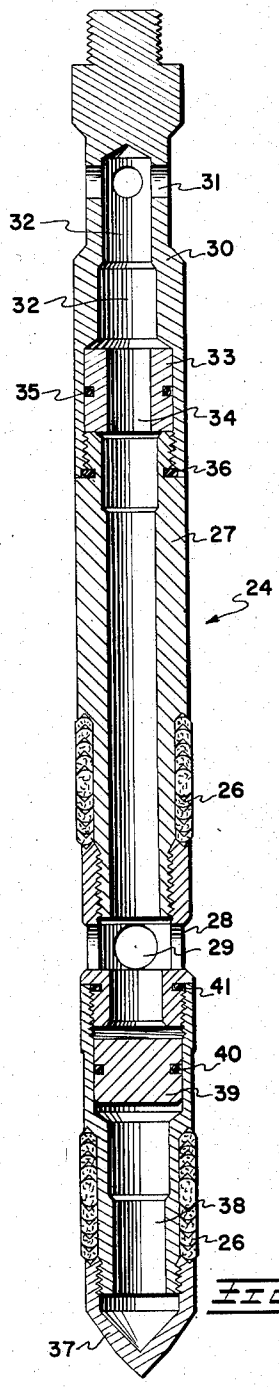
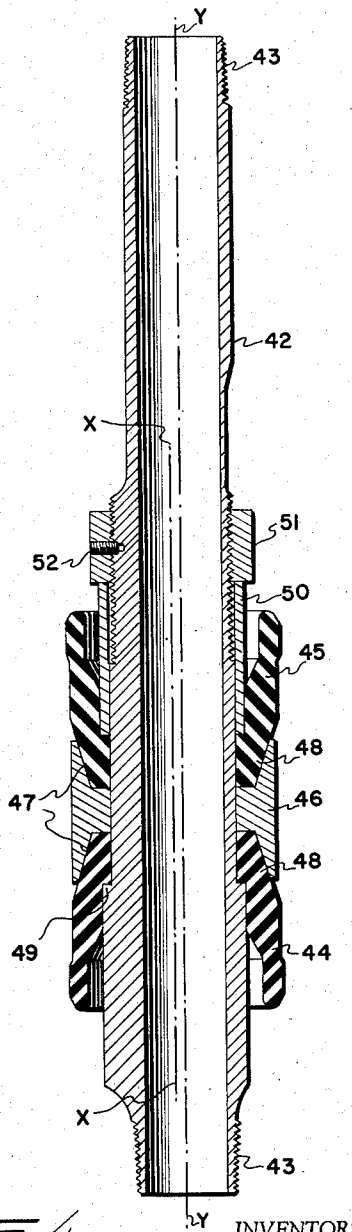


Fig. 4.

Fig. 5.



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APPARATUS FOR CONTROLLING THE FLOW OF FLUIDS IN A MULTI-STRATA WELL

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4 Claims. (Cl. 166—185)

This invention relates to the control of fluid flow in gas and oil wells. Particularly, this invention is concerned with apparatus for selectively controlling the flow of oil, gas or other fluid from a plurality of producing sands of a well, and for selectively controlling the injection of gas or other fluid into the several producing formations. This invention also relates to an improved packer structure particularly suitable for use in our flow control apparatus when used in a well of restricted cross section.

In certain locations, oil and gas productive formations are encountered in a series of layers at different depths below the surface of the earth, these layers being separated in various degrees by dense and impervious non-productive formations. In the production of oil and gas from a plurality of such producing sands by natural means or with the aid of artificial stimulation by injection of gas or other fluid, a serious need exists, in order to obtain maximum oil recovery, for controlling production rates from and/or injection rates into the individual producing formations of a single well.

In the past, various types of equipment and methods have been utilized for admitting fluid from one or more formations into a well production tubing. It has been usual to cement in casing, open up one or two formations and when they are depleted, to cement them off and open up a new formation. This requires that the well be killed with mud and worked over each time a change is made, which may be most injurious to the ability of the well to further produce or to receive injection fluid. Concentric strings of pipe have also been used, however, such equipment has, in general, been successful in isolating a maximum of but three intervals within a single well bore. The use of such equipment is obviously infeasible in wells located in areas where a single well may traverse more than three producing formations. The use of removable flow control means, such as sleeves having an orifice, located in the main string of pipe has also been suggested, but with such apparatus, the upper sleeves must be withdrawn before the lower sleeves can be introduced or withdrawn. By means of the apparatus of the present invention, the manifold deficiencies of the prior apparatus and methods are successfully overcome, and separate control of fluid flow from or into a plurality of producing strata in a single well bore is accomplished.

The apparatus of this invention may be suitably described by reference to its use in conjunction with a well bore which has been drilled through a plurality of vertically spaced producing formations. Generally, in such cases the formation surfaces exposed to the well bore are traversed by a cemented casing which has been perforated at the producing formations, leaving solid cemented casing across non-producing, substantially impervious strata. The apparatus of this invention includes a pipe string in the well and packing means forming seals between the pipe string and the well casing at a plurality of spaced points in the well. The packing

means may be positioned in the well so as to segregate individual producing formations or to divide a single producing formation into a plurality of separate producing areas. Enlarged tubing sections are placed in the pipe string adjacent packed-off producing formations. Each enlarged tubing section has a seat for a flow control member laterally offset from the axis of the pipe string. Flow control members are insertable into and removable from said seats and are sized so that they can pass through the portion of the enlarged tubing sections in vertical line with the pipe string.

By this arrangement, the amount of fluid passing through each flow control member opposite a producing formation can be controlled from the ground's surface simply by removing the member and regulating its rate of throughput. Since the valve seats are offset from the axis of the pipe string sufficiently to permit the passing of a flow control member down the pipe line as on a wire cable, the flow rates of from two to a great number of individual producing areas can be controlled without disturbing the flow control members of overlying producing strata or removing the pipe string from the well bore. Thus, with the apparatus of this invention, flow of fluid into or from each of a plurality of producing strata can be separately controlled to obtain maximum oil recovery with a minimum of expense.

The apparatus of this invention is illustrated in the accompanying drawings, which show a preferred embodiment of the invention, and flow control units and packers of suitable design for use in the apparatus of the invention.

Figure 1 shows diagrammatically a vertical sectional view of a well which has been equipped with the apparatus of the invention where a plurality of productive formations have been encountered in spaced relationship.

Figure 2 is a vertical section, with certain elements shown in full and others broken away in the interest of clarity, of an arrangement of the apparatus embodying the present invention adapted for concurrently controlling flow of fluid into and out of a plurality of producing strata by utilizing concentric pipes in a single well bore.

Figure 3 is a vertical sectional view illustrating the internal construction of a preferred form of enlarged tubing section with a flow control member.

Figure 4 is a vertical section illustrating in detail a preferred form of flow control member shown in Figure 3.

Figure 5 is a vertical section of a packer assembly suitable for use when the apparatus of this invention is utilized in conjunction with well bores of relatively narrow cross section.

In Figure 1, 10 represents the bore hole of a well drilled through a plurality of producing formations 11 which have spaced between them impervious formations 12. The well is cased by a casing 13 and a body of cement 14 is disposed between the well bore and casing 13. The well casing and cement have perforations in the portions traversing the producing formations as indicated in general at 15. Production string or piping 16 located within the well bore is illustrated diagrammatically as having been provided with enlarged tubing sections 17 containing flow control members (Figure 3), which are spaced in the string so that enlarged sections 17 will be opposite the producing formations 11. On the outside of the production string 16 are a plurality of packers 18 which close the production area 19 between the pipe string and the casing at each of the producing formations 11. These packers may be of any desired form which maintain a seal and provide producing areas 19.

The flow control members are located on valve seats

laterally offset within the enlarged tubing sections 17 sufficiently so that the flow control members can be separately inserted and withdrawn as with conventional wire line equipment without removal of the production string or interference with the operation of overlying flow control members. Thus, the employment of the apparatus of this invention as illustrated in Figure 1, makes possible the selective control of flow of oil, gas or other fluid into or from each of the various producing strata within a single well bore to obtain maximum recovery of well fluids.

Another embodiment of the apparatus of this invention is illustrated in Figure 2. This apparatus is advantageously employed to control simultaneously the flow of fluid injected into certain producing formations and removed from other producing formations of a plurality of vertically spaced producing formations within a cased well bore. The well assembly of Figure 2 comprises casing 13, cemented portion 14, perforations 15 located at producing formations 11, and production string 16 having enlarged tubing sections 17 and 17', and packers 18. The upper portion of production string 16 is formed of inner pipe 20 and outer pipe 21 which have substantially the same vertical axes, and the lower portion of the production string is formed of a single pipe 20' which is in flow communication with inner pipe 20. Inner pipe 20 is removable from and insertable into outer pipe 21 by means of conventional surface-operated, pipe-handling equipment. Lower enlarged tubing sections 17 are in flow communication with the lower portion of the producing string 20' and inner pipe 20, while upper enlarged tubing sections 17' are in flow communication with outer pipe 21 of the upper section of the producing string. Insertion and removal of the laterally offset flow control members is carried out in a manner similar to that in reference to the apparatus of Figure 1. However, in the case of the flow control members in upper enlarged tubing sections 17', inner pipe 20 must be removed before said members can be either inserted or removed. Thus, with the apparatus of Figure 2, injection fluid may be introduced into the lower producing formations, well fluids may be produced concurrently from upper producing strata, or vice versa, and at the same time the rate of flow of fluids into or out of each of the several producing strata can be completely controlled.

Figure 3 illustrates the construction of a preferred form of enlarged tubing section and a flow control member which may be inserted or withdrawn from a producing string with conventional wire line equipment. As shown, each enlarged tubing section 17 has an enlarged intermediate portion of greater internal cross-sectional area than the internal cross-sectional area at the ends of such sections. Tubing section 17 has a main flow channel 22 and a laterally offset elongated internal tubular area 23 located between its ends. This offset area provides a seat for a flow control member which takes the form of valve body 24 in the illustration. The exterior wall of offset area or flow control member seat 23 is provided with one or more orifices 25 which permit passage of fluids into and out of that area of seat 23 bounded by upper and lower valve body ring seals or packers 26. Such fluids are brought into communication with the main pipe string by traversing the interior of valve body 24. Rate of flow either into and out of the producing string is dependent upon the size of one or more orifices or beans (Figure 4) located within valve body 24. Valve body 24 is prevented from being dislodged by pressure of fluids from valve seat 23 by any suitable means, for instance, the latching means shown in U. S. Patent 2,679,903. Flow control member seat 23 is offset from the main flow channel 22 of tubing section 17 to a degree sufficient to permit the unrestricted passage of flow control members and suitable surface operated shifting tools, not shown, through the main flow channel to either higher or lower levels in the producing string without interfering with a seated flow control member.

Referring to Figure 4, cylindrical valve body 24 comprises hollow, cylindrical central body section 27 which at its lower end threadedly engages hollow cylindrical orificed section 28 having one or more orifices 29, and at its upper end threadedly engages upper cylindrical body section 30 having one or more orifices 31 in communication with central chamber 32. Seated within chamber 32 is removable orifice or cylindrical bean 33 providing passage 34. O rings 35 and 36 provide a seal between bean 33 and upper body section 30, and between body sections 30 and 27, respectively. The upper end of upper body member 30 is threaded for engaging a hold-down assembly, not shown. The hold-down assembly, which prevents displacement of the valve body by pressure of well fluids, may take the form of the assembly disclosed in U. S. Patent No. 2,679,903, or any other suitable mechanism. Threadedly engaged to cylindrical orificed section 28 is lower cylindrical body section 37 having a conical lower end. Within chamber 38 of lower body section 37 is a solid cylindrical member 39. O rings 40 and 41 provide a seal between bean 39 and body section 37, and between orificed section 28 and body section 37, respectively. Body sections 27 and 39 are provided with ring seals or packers 26 which provide a seal between valve body 24 and valve seat 23. Fluids flowing into or out of orifices 25 in valve seat 23 (Figure 3) pass through orifices 29 in orificed section 28, through the hollow core of the central body section 27, passage 34 in bean 33, chamber 32 and out of or into orifices 31 in upper body section 30.

It can be seen that flow of fluids through the valve body may be set at any desired rate by utilizing a bean having a passage which will provide the desired rate of flow. Rate of flow into or out of a particular producing formation may be altered by removing the valve body from the producing string with a suitable shifting tool on a wire line, disengaging upper body section 30 from central body section 27, removing the bean, substituting therefor a bean having an orifice of the size required to obtain the desired rate of flow, reengaging the body sections, and returning the valve body to its seat within the pipe string. A suitable tool for removing or inserting the valve body from or into offset section 17 is shown in U. S. Patent 2,679,903. By use of a solid bean or plug, a particular formation may be sealed off from the producing string.

In many instances, it may be desirable to utilize the apparatus of this invention in well bores of restricted cross-sectional area. Since, in this invention the enlarged tubing sections are laterally offset from the vertical axis of the main pipe string, it is often impossible to locate the pipe string in concentric relation to a well casing of such restricted cross-sectional area. In such instance, ordinary packers, which have resilient sealing cups concentric to the pipe string will not provide an adequate seal to segregate the several producing formations. We have now devised a packer which can be used with pipe strings which are not concentric to the well bore, and are particularly useful to provide an excellent seal to segregate producing formations when the apparatus of this invention is utilized in well bores of such restricted cross-sectional area that the producing string cannot be placed concentric to the well casing.

A packer suitable for accomplishing the above purpose is illustrated in Figure 5. In this packer, a firm seal is obtained between the resilient sealing cups of the packer and the well casing by expansion of the sealing cups due to the pressure of well fluids. The packer comprises a tubular mandrel 42 exteriorly threaded at each end as indicated at 43 to adapt it for securement to a pipe string. For a considerable portion of the length of the mandrel, axis X of the outer circumferential surface is laterally displaced to a desired degree from axis Y of the inner

circumferential surface of the hollow core of the mandrel. By reason of this lateral displacement of the axis of the outer circumferential surface, downwardly directed resilient packer cup 44 and upwardly directed resilient packer cup 45, which have their axes along the axis of the outer circumferential surface of the mandrel, are accordingly laterally displaced to the degree necessary to place them in substantially concentric relationship to the well bore and thus form a tight seal around the entire circumference of the well casing, although the pipe string is not in concentric relation to the casing because of the lateral offset of the enlarged tubing sections.

Resilient packer cups 44 and 45 are circumferentially anchored to mandrel 42 by annular thimble 46 which is slideably mounted on mandrel 42 and has downwardly and inwardly tapered surfaces 47 which slideably engage complemental tapered surfaces 48 of packer cups 44 and 45. Longitudinal movement of packer cups is prevented by annular flange 49 of mandrel 42 which engages packer 44, slideable sleeve 50 which engages packer 45, and by lock nut 51 which threadedly engages mandrel 42 and forces sleeve 50 toward annular flange 49. Lock nut 51 is provided with set screw 52 to prevent rotation by the lock nut.

The distance that the coincident axes of the cups and outer surface of the mandrel must be laterally displaced from the axis of the hollow core of the mandrel, which is substantially coincident with the axis of the producing string, will depend upon several factors including the degree of lateral displacement of the enlarged tubing sections and the cross-sectional area of the well bore casing with which the apparatus of the invention is used. In certain instances, a lateral displacement of the axis of the resilient cups from the axis of the main pipe string of about one-eighth inch may be sufficient to obtain a tight seal. Under different circumstances a considerably larger displacement may be necessary.

Suitable packers for employment at the upper and lower extremities of a well pipe string (see Figures 1 and 2) usually have resilient sealing cups facing in but a single direction since such packers are generally adjacent impervious strata in the well bore and not between two producing formations, and thus are subjected to forces due to pressure of well fluids acting in but a single direction. The uppermost packer will have one or more downwardly directed sealing cups and no upwardly directed cups, and the bottom-most packer will usually have only upwardly directed sealing cups, said sealing cups facing producing formations. Packers of this type which are suitable for use in a well wherein the pipe string is not concentric to the well bore may take the form of the packer of Figure 5 in which either the upwardly or downwardly directed packer has been omitted. In a packer of this design, annular thimble 46 need have but a single downwardly and inwardly tapered surface 47, rather than two such surfaces as illustrated, which slideably engages the complemental tapered surface 48 of the single packer.

In a well bore equipped with a greater number of either upwardly or downwardly directed resilient sealing cups, each subjected to pressure of well fluids, the pipe string often has a tendency to be longitudinally displaced with respect to the well bore by pressure of well fluids. For example, if there are a greater number of downwardly directed sealing cups, the pipe string will tend to be forced out of the well. It has been found that if each producing area segregated by packers is bounded by a pair of sealing cups, i. e., an upper downwardly directed cup and a lower upwardly directed cup, upwardly and downwardly directed (see Figures 1 and 2), forces created by the pressure of well fluids in the producing area are effectively balanced by the opposing faces of the pair of sealing cups, and the tendency of the pipe string to be driven either from or further into the well is effectively prevented.

We claim:

1. In an apparatus for controlling flow of fluids injected into and removed from a plurality of vertical spaced producing formations within a cased well bore and which comprises a pipe string in the well, an enlarged tubing section in the pipe string adjacent each of a plurality of said producing formations and communicating therewith, said enlarged tubing sections having a flow control member seat and a flow control member removably associated therewith for controlling fluid flow between the pipe string and the respective producing formations, said seats being laterally offset from the vertical axis of the pipe string sufficient to permit the raising and lowering of said flow control members through the pipe string and past flow control member seats in overlying enlarged tubing sections, and wherein said pipe string is not concentric to the well bore by reason of the lateral offset of the flow control member seats in the enlarged tubing sections, a plurality of packing means comprising a tubular mandrel having the longitudinal axis of its outer circumferential surface laterally displaced from the longitudinal axis of its inner circumferential surface, a resilient annular sealing means fixedly engaging the laterally displaced outer circumferential surface of the mandrel, the sealing means having its axis substantially coincident with the laterally displaced axis of the outer circumferential surface of the mandrel, and means for preventing longitudinal displacement of the sealing means with respect to the mandrel, whereby seals are formed between the pipe string and the well casing at a plurality of vertically spaced points in the well.

2. An apparatus for controlling the flow of fluid between a plurality of vertically spaced formations and a pipe string within a well bore which comprises a pipe string in the well, packing means forming seals between the pipe string and the well at a plurality of vertically spaced points in the well to segregate a plurality of formations, a laterally enlarged tubing section in the pipe string between said packing means and adjacent each of a plurality of said formations, a flow control member socket in said laterally enlarged sections, said sockets being in communication with the bore of said pipe string and having an opening communicating externally of said pipe string and with the adjacent formation, a flow control member having an internal bore and removably disposed in each of the plurality of flow control member sockets, said flow control members being adapted to be removed and inserted in said flow control member sockets by a well tool insertable into said pipe string, said sockets being laterally offset from the vertical axis of the pipe string sufficient to permit the raising and lowering of said flow control members through the pipe string and past flow control member sockets in overlying enlarged sections, a first opening in said flow control members communicating with the bore of the respective flow control member and the bore of said pipe string, a second opening in said flow control members displaced from said first opening and communicating with the bore of its respective flow control member and the opening in its flow control member socket communicating externally of said pipe string and with the adjacent formation, flow preventing means disposed between the respective flow control member sockets and flow control members intermediate the first and second openings in the flow control members, a removable member positioned in the bore of the respective flow control members between the said first and second openings and having a restricted orifice of predetermined size smaller than the bore of its respective flow control member to provide a desired rate of flow between the pipe string and the respective formations, and means to sealingly separate the internal portion of the flow control member sockets communicating with said second openings from fluid communication with

the bore of said pipe string except through said orifice members.

3. The apparatus of claim 2 in which the last named means is a lower end of said sockets closed from communication with said pipe string below said flow preventing means.

4. An apparatus for controlling the flow of fluids between a plurality of vertically spaced formations and a pipe string within a well bore which comprises a pipe string in the well, packing means forming seals between the pipe string and the well at a plurality of vertically spaced points in the well to segregate a plurality of formations, a laterally enlarged tubing section in the pipe string between said packing means and adjacent each of a plurality of said formations, a tubular flow control member socket in said laterally enlarged sections, said sockets being in communication at an upper portion with the bore of said pipe string and having an opening in a lower portion communicating externally of said pipe string and with the adjacent formation, a tubular flow control member removably disposed in each of the plurality of flow control member sockets, said flow control members being adapted to be removed and inserted in said flow control member sockets by a well tool insertable into said pipe string, said sockets being laterally offset from the vertical axis of the pipe string sufficient to permit the raising and lowering of said tubular flow control members through the pipe string and past flow control member sockets in overlying enlarged sections, an opening in an upper portion of said tubular flow control members communicating with the bore of the respective flow control member and the bore of said pipe string, an opening in a lower portion of said tubular flow control members communicating with the bore of the respective flow control member and the opening in the lower portion of its flow control member socket, flow preventing means disposed between the respective flow control member sockets and flow control members intermediate the upper and lower openings in the flow control members and above said opening in the lower portion of the flow control member sockets, means to prevent direct fluid flow between the bore of the flow control members and the bore of said pipe string below said flow preventing means, and a removable member positioned in the bore of the respective flow control members between the said openings in the upper and lower portions of said flow control members and having a restricted orifice of predetermined size smaller than the bore of its respective flow control member to provide a desired rate of flow between the pipe string and the respective formations.

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