May 14, 1968 S. M. ZANDMER 3,382,926

WELL COMPLETION DEVICE WITH ACID SOLUBLE PLUG

Filed Jan. 5, 1966 2 Sheets-Sheet 1

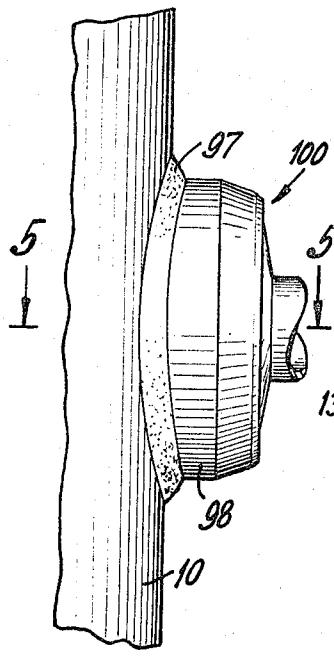


FIG. 1

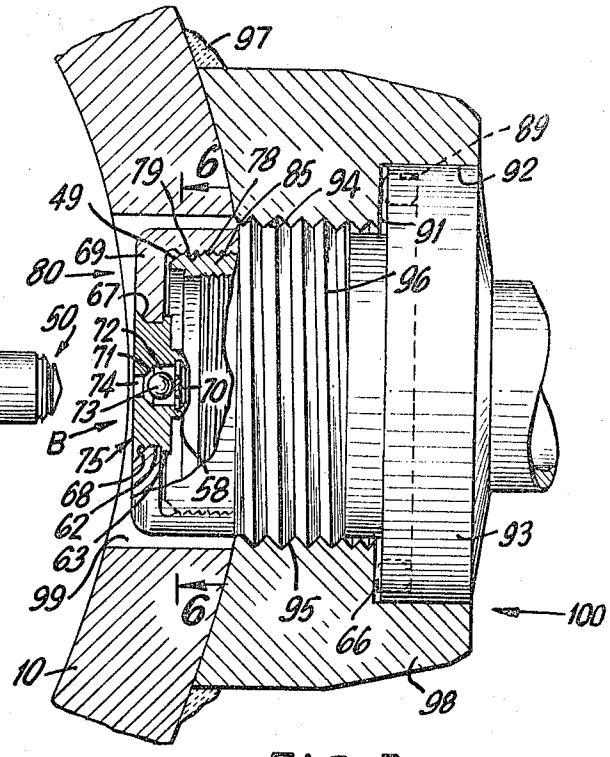


FIG. 5

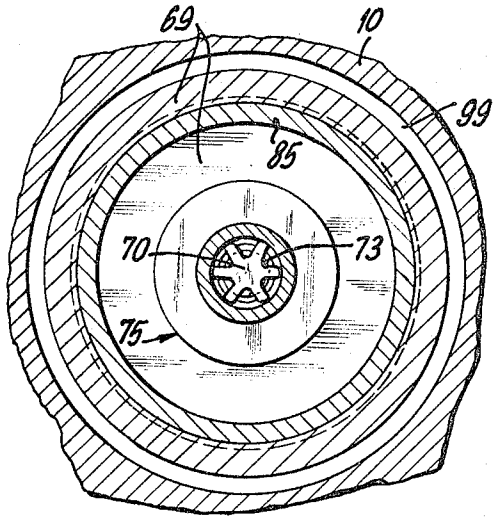


FIG. 6

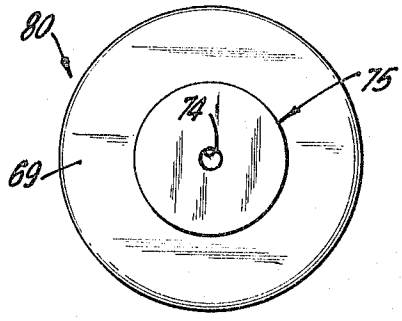


FIG. 7

INVENTOR.
SOLIS MYRON ZANDMER

BY

Moses, McGlew & Toren
ATTORNEYS.

May 14, 1968 S. M. ZANDMER 3,382,926

WELL COMPLETION DEVICE WITH ACID SOLUBLE PLUG

Filed Jan. 5, 1966 2 Sheets-Sheet 2

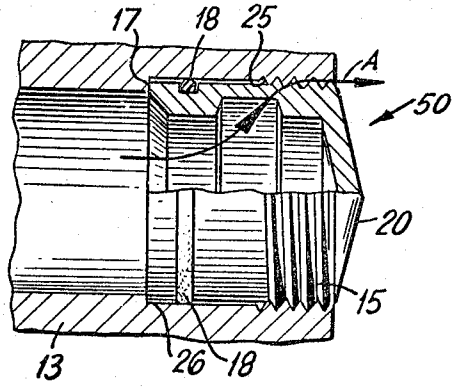


FIG. 4

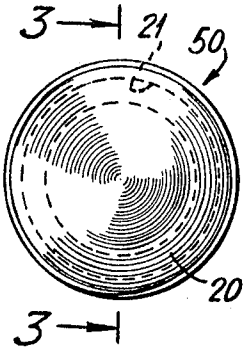


FIG. 2

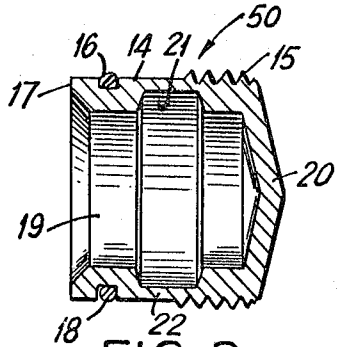


FIG. 3

INVENTOR.
SOLIS MYRON ZANDMER
BY
Moses, McGlew and Toren
attorneys

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WELL COMPLETION DEVICE WITH ACID SOLUBLE PLUG

Solis Myron Zandmer, 111 Glen Ave., Banff, Alberta, Canada

Continuation-in-part of application Ser. No. 457,290, May 20, 1965. This application Jan. 5, 1966, Ser. No. 518,884

15 Claims. (Cl. 166—100)

This is a continuation-in-part of my application Ser. No. 457,290 filed May 20, 1965.

This invention generally relates to well completion apparatus of the kind wherein duct-forming elements are secured to a bore hole casing or liner and may be caused to project laterally from the casing to make contact with a producing zone of the formation.

Considered from one aspect, the invention is particularly directed to closures for such duct-forming elements of the kind wherein an acid soluble metal screw plug is threaded into an end of a tube, sleeve, conduit or the like duct or passage forming device (hereinafter collectively being referred to as "tube") of the duct-forming element for temporarily closing the tube and wherein, upon introduction of acid into the tube, the screw plug is at least partially dissolved or disintegrated in order to become dislodged from, and thus to clear, the respective tube end.

Considered from another aspect, the invention is concerned with valve-controlled flow-restricting constructions for use in connection with such duct-forming elements for temporarily blocking the flow of fluid in one direction through a tube, while permitting limited flow of fluid into the tube in the opposite direction, the flow-restricting means being made of acid-soluble metal to cause disintegration of the flow-restricting means by acid.

Until recently, bore hole casings or liners have been set in bore holes by a cementing process in which a cement slurry is forced down through the casing and then upwardly around the outside of the casing to fill the annular space between the exterior casing surface and the surrounding wall of the formation. After solidification of the cement, communication between the casing and the producing zone was established by explosive perforation of the casing, e.g. by means of bullets or shaped charges which also penetrated the hardened cement to form passageways or ducts therethrough. This procedure is unsatisfactory as the bullets or charges tend to crack the cement around the passageways, thereby causing vertical communication, to wit, up and down movement around the casing from one perforation to another. This, in turn, prevents later selective treatment through each perforation to the formation at the end of each duct or perforation, since injected treating material could travel up or down through cracked cement without permitting selective control at the injected places; i.e., the stratum of the formation at the end of each duct.

More recently, an improved method and device for establishing communication between the casing and the producing zone has been suggested. According to this suggestion, a plurality of duct-forming devices are welded or otherwise secured to the outside of the casing in alignment with holes machined into the casing wall. These duct-forming devices comprise telescoping tubes or sleeves which are in a retracted position during the positioning of the casing in the bore hole. When contact with a producing zone is to be made, these telescoping tubes are caused to project substantially horizontally toward the formation wall to make contact with the pay zone and to establish a permanent link between the pay zone and the casing. The cement slurry is introduced into the space

between the casing and the formation wall either before or after the lateral telescoping of the tubes so that the cement sets around the tubes and the casing. The telescoping tubes of the duct-forming devices, as previously proposed, are made of steel or the like acid resistant metal and the outer tube ends which ultimately contact the producing formation are blocked by acid soluble metal plugs which are lodged within the tube in a sealing manner so as temporarily to prevent passage of material through the tube. When communication between the pay zone and the interior of the casing is to be established, acid is introduced into the casing and into the laterally extending telescoping tubes to cause dissolution of the plugs.

Extensive experiments and tests have established that, irrespective of the strength and the nature of the acid introduced into the tubes, the plugs do not readily and rapidly dissolve unless proper circulation is ultimately provided for the acid. This is so because acid which attacks a surface of a solid acid soluble material dissolves first the outermost layer or stratum of the material whereafter the acid is prevented from effectively exerting its dissolving activity due to the dissolution or reaction product or products which have a tendency to form a protective barrier or cushion between the surface to be dissolve and the acid. For this reason, fresh or unconsumed acid is prevented from contacting the subjacent stratum of acid soluble material. This phenomenon is particularly pronounced in respect to acid attacking relatively small areas. Thus, for example, if one surface of a magnesium plate or disc is wetted with acetic acid, the acid almost instantaneously dissolves a thin surface layer of the wetted surface, whereafter, however, the acid is rendered substantially inactive due to the formation of magnesium acetate which tends to lodge itself as a barrier between the surface to be attacked and unconsumed acid, thereby preventing further effective attack of the unconsumed acid on the undissolved material. For this reason, it has been found that an excessive time is required to dissolve the metal plug in the tube referred to so as to cause dislodgement thereof from the tube.

Accordingly, it is one object of this invention to provide for a closure construction wherein the end of the acid resistant metal tube of the duct-forming element which upon projection is intended to make contact with the producing formation is temporarily blocked by an acid soluble metal plug of a construction that overcomes the prior art drawbacks referred to and that permits effective dissolution of the plug by the acid and ensures sufficient ultimate circulation and movement of the acid during the dissolution procedure so as to cause disintegration and dislodgement of the plug within reasonable time limits.

Another object of the invention is to provide an acid soluble screw plug of the indicated kind having an external thread which meshes with a complementary interior thread of the tube and which is provided with means for effectively sealing the plug against the interior tube wall without impeding the action of dissolving acid.

Once the acid has eaten away a sufficient portion of the plug to dislodge it from the tube end, the outside pressure acting on the outer end face of the plug tends to hurl the plug towards and into the interior of the tube if the outside pressure is greater than the pressure prevailing within the tube.

Accordingly, it is still a further object of the invention to provide a closure construction of the kind referred to which has means for retarding the inward movement of the plug until the major portion of the plug has been consumed.

In the previously suggested well completion apparatus

with which this invention is concerned, the duct-forming devices are welded or otherwise secured to the outside of the bore hole casing in alignment with holes machined into the casing wall. When contact with the producing zone is to be made, the telescoping tubes are projected from their retracted position to extend laterally from the exterior of the casing toward the formation wall. This is accomplished by pressurizing the casing. Since the rear end of the tube of each duct-forming device, to wit, the end which is in alignment with the respective hole in the casing wall, communicates with the interior of the casing while the front end of the tube, to wit, the end which is intended to contact the producing formation, is closed by the screw plug, pressure builds up within the interior of the tube. This pressure must be sufficient to overcome the retaining force of retaining means or the like to propel the telescoping tubes in a direction away from the casing and toward the producing formation. In practice, it has been experienced that due to malfunctioning or other mishaps as, for example, faulty assembly of the duct-forming devices, some of the tubes are sometimes prematurely propelled toward the producing formation. This, for example, may happen during the lowering of the casing into the bore hole. If a tube has thus been prematurely projected away from the casing, the front portion of the tube which contains the terminal screw plug may be torn off by frictional contact with the formation wall with the result that free communication is established between the interior of the casing and the space surrounding the casing. This, of course, is highly undesired since it prevents effective build-up of pressure within the casing and may cause reentry of liquid cement from the outside into the interior of the casing.

Accordingly, it is a further object of this invention to provide a construction wherein the rear end of each duct-forming device is fitted with a flow-restricting safety means which permits restricted flow of fluid from the interior of the casing toward the terminal screw plug, but which prevents flow of fluid through the tube into the interior of the casing.

A still further object of the invention is to provide a safety device of the indicated kind which, after positioning of the casing with its duct-forming devices in the bore hole and after projection of the tubes toward the producing formation, can at least partially be disintegrated or dissolved by acid so as to permit substantially unrestricted flow through the tubes in both directions.

A still further object of the invention is to provide a safey device of the indicated kind which is in the form of a screw cap and which is constructed so that after the flow-restricting means have been dissolved by acid, a seat surface is exposed on the cap at the location of the associatesd casing hole to permit blocking of the communication between the interior of the casing and the tube of the duct-forming device by means of a ball-shaped sealing means, commonly referred to as a "ball sealer," which is suspended within liquid container within the casing and thus has a tendency to be urged against said seat when liquid flows from the interior of the casing through the hole.

Generally, it is an object of this invention to improve on the art of well completion apparatus having duct-forming elements as presently practiced.

Briefly, and in accordance with the first indicated aspect of this invention, the acid soluble metal plug is constructed in the form of a generally cylindrical externally threaded body. The body is formed with an interior bore or cavity which extends inwardly from the rear end of the plug toward the front end, but which terminates short of the front end to leave a front portion of substantial metal layer thickness. The peripheral wall of the body which defines said bore or cavity has an annular zone of substantially reduced radial thickness which forms a diaphragm-like strip. When the plug is to be dissolved, acid is introduced into the rear end of the plug. The acid enters the bore or cavity of the plug and rapidly dissolves

the metal in the region of the annular zone of reduced radial thickness, to wit, the diaphragm strip. The acid then exits outwardly through the opening in the diaphragm zone thus formed and flows along the external threads of the plug to cause rapid dissolution and disintegration of the plug.

According to a further feature of the invention, no chemical sealant is used for sealing the plug against the wall of the tube, but the sealing is advantageously accomplished by an O-ring which is positioned in a groove located behind the threads and adjacent the rear end of the plug. As is known, O-rings are extremely efficient sealing means and in fact the sealing action of an O-ring is the greater the greater the pressure. Therefore, the provision of the O-ring adjacent the rear end of the plug effectively prevents entry of matter into the tube from the outside. The O-ring moreover blocks escape of material from the tube interior toward the outside. The diaphragm strip which is thus first dissolved and eaten through by the acid should be located ahead of the O-ring, to wit, between the O-ring and the front end of the plug so that the flow of the acid is not obstructed.

The annular diaphragm zone of substantially reduced radial thicknss is preferably formed by cutting or working a relatively narrow groove into the interior body wall which defines the bore referred to. This groove should have a depth so that the remaining wall portion is extremely thin but yet of a strength sufficient to withstand the pressures acting on the plug. Since the diaphragm strip portion is protected from erosion and other forces which may prematurely cause its destruction, the diaphragm may be extremely thin. In practice, it has been esetablished that at bore hole depth of 15,000 feet for which duct-forming devices of the indicated kind are presently designed, excellent results are obtained if the thickness of the diaphragm strip is about between 0.030 to 0.040 inch.

After the acid has eaten through the diaphragm strip and has consumed a portion of the external threads, the plug becomes dislodged from its threaded engagement with the tube. In accordance with a further feature of the invention, the tube is provided with retarding or retaining means which are located behind the rear end of the plug and which advantageously may comprise a flange or shoulder projecting from the interior wall of the tube in an inward direction so as to provide a seat for the plug against which the plug rests and which prevents inward movement of the plug. Thus any tendency to urge the plug inwardly is effectively counteracted. Only after substantially the entire plug has been consumed by the acid will plug fragments be able to clear the shoulder to enter the interior of the tube.

Turning now to the second aspect of this invention, the flow-restricting means advantageously takes the form of a safety cap which is screwed or otherwise secured to the rear end of the duct-forming device at a location substantially flush with the interior wall of the casing and coinciding with its associated hole. A narrow passage is formed through the cap, conveniently in the center thereof, with a check valve arranged on the cap to permit flow of fluid from the interior of the casing into the tube of the duct-forming device while preventing flow of fluid from the duct-forming device through the passage into the interior of the casing. The check valve is preferably of the ball check valve type.

While it is feasible to make the entire cap of acid-soluble metal, such as zinc or magnesium, according to a preferred embodiment the cap proper is made of steel in the same manner as the duct-forming device proper, the cap, however, having a central, circular insert of acid-soluble metal, preferably zinc. The valve controlled passage is located in the acid-soluble insert and after the telescoping tubes have been projected into their operative position by pressurizing the casing, whereby fluid flow through the narrow passage in the insert causes projection

of the tube, acid is inserted into the casing to dissolve and integrate the insert. The fluid which is used for pressurizing the casing may contain weak acid. The weak acid requires, however, a relatively long time to dissolve the insert with its valve, so that sufficient time is available properly to eject the telescoping tubes. The dissolution of the insert by the acid is, of course, facilitated by the provision of the passage through the insert since this enlarges the contact surface available to the acid for attack. After the insert, including the valve controlled passage, has been destroyed by the acid, substantially unrestricted communication between the interior of the casing and the duct-forming device is thus established, since the remainder of the cap then defines a relatively large passageway.

According to a preferred embodiment of the invention, the acid-soluble insert of the cap forms an inwardly bevelled or conical surface which bears against a complementarily shaped surface of the acid resistant portion of the safety cap. After the acid-soluble insert has been dissolved by the acid, there thus remains the acid resistant cap portion which defines a passageway having an interior diameter corresponding to the diameter of the acid-soluble insert and forming a conical peripheral seat surface. If this enlarged passage or passageway, during the operation of the well, is to be closed for any reason whatsoever, a ball sealer can be floated down and suspended within liquid in the casing to lodge itself against the conical surface in a sealing manner. The diameter of the acid-soluble insert and thus of the passageway formed upon dissolution should, however, be smaller than the diameter of the telescoping tubes to prevent undesired retraction or entry of the tubes into the interior of the casing should they in any manner become dislodged from their retaining means.

The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings in which there is illustrated and described a preferred embodiment of the invention.

In the drawings:

FIG. 1 is a fragmentary side elevation of a bore hole casing having a duct-forming device secured to its exterior surface, the duct-forming device including a terminal tube or sleeve which is closed by an acid-soluble metal screw plug in accordance with this invention. In order not to crowd the drawing, those elements and mechanisms of the duct-forming device which do not form part of this invention have been omitted;

FIG. 2 is an end view of the front end of the inventive screw plug;

FIG. 3 is a section taken along line 3—3 of FIG. 2;

FIG. 4 illustrates, partly in section and partly in side elevation, the screw plug as screwed into a sleeve or tube such as shown in FIG. 1;

FIG. 5 is a sectional view along line 5—5 of FIG. 1 on enlarged scale;

FIG. 6 is a sectional view along line 6—6 of FIG. 5; and

FIG. 7 is an end view of the safety cap of FIG. 5 seen in the direction of arrow B.

Referring now to the drawings, and in particular to FIGS. 1 and 5, a duct-forming device, generally indicated by reference numeral **100**, is secured to the external surface of a bore hole casing **10**. For this purpose, the bore hole casing **10**, which has a machined hole or opening **99** as seen in FIG. 5, is provided with a nipple or mounting boss **98** which is welded to the exterior casing surface as indicated by reference numeral **97**. The duct-forming device **100** has a hollow, cylindrical rear mounting portion **96**, whose external thread **95** meshes with the internal thread **94** of the nipple **98**. Rear mounting portion **96** of the duct-forming element **100** terminates in a front collar or flange portion **93** which fits into an annular space **92** defined by the shoulder **91** formed by the nipple **98**. A sealing means, such as an O-ring **66**, may be inserted between the collar **93** and the shoulder surface **91** of the nipple **98**, in order properly to seal the duct-forming element against the nipple **98**. For this purpose, the collar **93** is provided with an annular groove **89** as seen in FIG. 5. The general construction of the duct-forming device has not been illustrated, but may correspond to that disclosed in U.S. patent application 128,609, now Patent No. 3,245,472, patented April 12, 1966.

The duct-forming device **100** projects laterally from the casing **10** and includes an outer or terminal inwardly threaded tube or sleeve **13** into which is threaded a screw plug generally indicated by reference numeral **50**. The screw plug **50** is illustrated as not being fully screwed into the tube **13**.

The construction of the screw plug is illustrated in detail in FIGS. 2 and 3. It will be noted that the screw plug **50** has a body portion **14** which is externally threaded as indicated by reference numeral **15**, the external threads extending over about one half of the length of the plug.

An external peripheral groove **16** is cut into the plug adjacent its rear end **17** and an O-ring **18** of customary construction is lodged within the groove.

The interior of the body portion **14** is hollowed out to form an interior cavity or bore **19** which extends from the rear end **17** towards the front end **20** but terminates short thereof. The bore **19** should not extend too far towards the front since the thickness of the front end **20** must be sufficient so as to be able to withstand the pressures which act on the free surface of the front end **20** from the outside. The thickness of the front end **20** of the plug **50** should also be relatively substantial since the front surface of the plug, during the lowering of the casing to near the bottom of the well bore, will consistently rub against the formation wall so that it must be able to withstand substantial impact, abrasion and friction forces. In accordance with the invention, an internal groove **21** is formed in the body portion **14** which groove **21** communicates with the bore or cavity **19** and forms a body wall portion **22** of substantially reduced radial diameter. Wall portion **22** of the plug is thus weakened and constitutes in fact a diaphragm-like strip. The diaphragm **22** is subject to rapid attack and destruction by acid. From a practical point of view, experiments have demonstrated that for screw plugs of the indicated kind to be used in duct-forming devices at well depth of about 15,000 feet, the thickness of the zone **22** or diaphragm should be between about 0.030 and 0.040".

FIG. 4 illustrates the screw plug of FIGS. 2 and 3 as screwed into a conduit or tube such as the tube **13** of FIG. 1. The tube **13** is provided with an interior thread **25** which meshes with the exterior thread **15** of the plug. Due to the provision of the O-ring **18** lodged within the groove **16** of the plug, effective sealing between the plug **50** and the tube **13** takes place, thereby preventing entry of matter from the outside into the interior of the tube and at the same time preventing penetration of matter from the interior of the tube towards the outside.

It will be noted that tube **13** forms an annular shoulder portion **26** which provides a seat for the rear end **17** of the plug.

While the tubes should be of acid resistant material such as steel or steel alloys, the plug must be made from an acid-soluble metal such as, for example, zinc, magnesium or aluminum or alloys of such metals.

The plug is usually screwed into the tube by means of a screw driving tool such as a screw driver and for this purpose the front end face **20** of the plug is originally provided with a slot. After the screw plug has been threaded into the tube, the slot is removed by grinding or the like machining of the end surface.

Referring now to FIGS. 5 through 7, it will be noted that the hollow threaded rear mounting portion **96**, which is screwed into the nipple **98**, has an exteriorly threaded

end portion 85. End portion 85 extends into the hole 99 formed in the casing wall 10. In accordance with the second aspect of the invention, a safety cap, generally indicated by reference numeral 80, has an internal thread 79 on a flange portion 49 which meshes with the external thread 78 of the end portion 85. The safety cap 80 may thus be screwed onto the end portion 85 and removed therefrom at will. FIGS. 5 and 6 show the cap in the operative position in which it is screwed onto the end portion 85. Cap 80 consists of steel or the like acid-resistant material, but has a central insert generally indicated by reference numeral 75, which is made of an acid-soluble metal such as zinc, magnesium or aluminum. The preferred metal, however, is zinc, since it has the most desirable characteristics in respect to its resistance to the various pH values which may prevail in the well completion apparatus before the insert is to be dissolved by acid.

A passage 74 traverses the insert 75 and is provided with a ball check valve as seen in FIGS. 5 and 6. The ball check valve comprises a ball 73 which is lodged in a valve chamber 72 which in essence is an enlarged portion of the passage 74. The seat for the ball is provided by a conical surface 71 while the ball is retained within the chamber 72 by means of a star-like plate 70 as best seen in FIG. 6. The plate 70, in turn, is held in place by a bent-over flange portion 58 of the insert 75. Of course, different means for retaining the ball within the chamber could be provided.

The acid-resistant body portion 69 of the cap 80 forms a conical or bevelled surface 68 against which bears the complementarily shaped conical or bevelled surface 67 of the acid-soluble insert 75. The acid-soluble insert 75 is held in position within the acid-resistant body portion 69 by means of an outwardly projecting flange 63 which projects beyond the shoulder 62 of the acid-resistant cap portion 69.

As previously mentioned, the star-shaped plate is held in position by a bent-over flange or retaining portion 58. In practice, the acid-resistant portion 69 of the cap is first manufactured with a passageway of a diameter slightly smaller than the diameter of the acid-soluble insert 75, whereafter the acid-soluble insert is pressed into the passage. By hammer action or the like, the flange 63 is then formed to retain the acid-soluble insert securely within the cap structure.

Cap 80 acts as a valve-controlled flow-restricting means since, due to the provision of the ball valve, fluid which is introduced under pressure into the casing 10 passes through the narrow passage 74 and through the ball check valve into the interior of the duct-forming device 100. By contrast, due to the provision of the ball 73 and its conical seat 71, any pressure exerted onto the ball from within the duct-forming device, urges the ball against the seat 71, thereby preventing entry of fluid into the interior of the casing.

The operation of the device is as follows:

In respect to the safety cap 80.—After the casing 10 has been positioned within the bore hole and a cement slurry or the like has been pumped through the lower open end of the casing to envelope the casing and to fill the space between the exterior of the casing and the wall of the formation, the pressure within the casing is increased to a value so as to overcome the tube retaining means and to propel the telescoping tubes of the duct-forming devices through the cement slurry and toward the wall of the formation to make contact therewith. The fluid which is used for this purpose enters the passage 74 and since the check valve permits flow in the direction toward the screw plug 50, the retaining force of the retaining means which has prevented the projection of the telescoping tubes is overcome by the fluid pressure. However, in the event that the portion of the duct-forming device 100 extending beyond the collar 93, including the screw plug 50, should have prematurely been ejected and been torn or broken off due to faulty assembly or the like, entry of any material into the interior of the tube is prevented by the ball check valve since the ball, upon being subjected to pressure emanating from within the duct-forming device or from the outside, is urged against its seat 71 to block communication between the duct-forming device and the interior of the casing.

Further, even if the front portions of one or several duct-forming devices are broken off, pressure can still be built up within the casing to a sufficient value to eject the remaining devices. This is so because leakage through the narrow passages in the inserts of the broken off elements can be easily compensated for by increasing the pumping speed. By contrast, in the prior art constructions wtihout safety cap, the breaking off of a single duct-forming element resulted in a relatively large passageway from the casing to the exterior which seriously interfered with the operation.

Once the casing has been installed and the duct-forming tubes have been properly propelled into contact with the wall of the formation, acid is introduced into the casing to eat away and dissolve the acid-soluble insert 75, whereby a relatively large passageway is formed in the body portion 69 corresponding to the size of the insert 75. If, at a later stage during operation of the well, communication between the interior of the casing and the duct-forming device is again to be blocked, a ball sealer can be floated down the casing interior, whereby the ball sealer will be pressed against the conical surface 67 of the acid-resistant portion 69 of the cap 80 to again block the communication.

The provision of the safety cap 80 has also additional advantages in the operation of the well completion apparatus: After the telescoping tubes have been propelled toward the wall of the formation and the pressure is released within the casing, the presence of the acid-resistant portion 69 of the cap 80 effectively prevents entry into the interior of the casing of duct-forming telescoping tubes which have become dislodged or been broken off from their moorings. This is so because, as seen in the drawings, the tubes have a larger diameter than the diameter of the passageway which is formed after the acid-soluble insert has been eaten away. Generally, handling and operation of the wall completion device is greatly facilitated by the provision of the safety cap 80 since it permits effective control of the device in a superior manner.

In respect to the acid-soluble plug.—After the tube 13 with the plug 50 screwed thereinto has been moved from its retracted position within the casing 10 to the extended or projected position shown in FIG. 1, and the insert has been disintegrated by the acid, the acid enters the tube 13. If the plug 50 is made of magnesium or zinc, acetic acid will normally be used or other organic or mineral acids may be employed. The acid thus enters the bore or cavity 19 of the plug and attacks the wall defining the cavity. Due to the provision of the groove 21 defined by the thin diaphragm wall portion 22, the diaphragm 22 is rapidly eaten through by the acid. The formation of the groove and its particular shape facilitate the acid attack on that region due to local accumulation of acid which speeds up the dissolution of the diaphragm zone. The acid, after having caused disintegration of the wall portion 22, flows within and around the valleys of the threads of the plug 50, as indicated by the arrow A. Since no chemical sealant is introduced between the meshing thread surfaces 15 and 25, the flow of the acid is unobstructed and rapid disintegration of the external surface of the plug 50 is thus caused. As soon as the threads 15 have been consumed to such an extent as to become dislodged from their mating engagement with the threads 25 of the tube 13, the external pressure acting on the front end 20 of the plug may urge the plug 50 towards the interior of the tube if this pressure exceeds the pressure within the tube. Due to the provision of the shoulder 26, dislodgment of the plug is, however, prevented. The presence of the O-ring 18 prevents the acid from reaching the rear end of the

plug so that the front portion of the plug is consumed before the acid eats around the O-ring. Therefore, no large fragments of the plug are hurled towards the interior of the tube, 13, but only small pieces are flushed inwardly which may be formed by the disintegration of the plug.

While specific embodiments of the invention have been shown and described in detail to illustrate the application of the inventive principles, it will be understood that the invention may be embodied otherwise without departing from such principles.

What is claimed is:

1. In well completion apparatus of the kind wherein a bore hole casing is adapted to be positioned in a bore hole and duct-forming devices of acid-resistant metal are secured to the casing in alignment with holes machined in the casing wall, each duct-forming device being capable of being laterally extended from the casing for making contact with a producing formation and wherein each duct-forming device includes a terminal sleeve whose outer end is blocked and closed by an acid-soluble metal pluug which upon introduction of acid into the sleeve is at least partially dissolved to become dislodged from its associated sleeve, the improvement which comprises that the acid-soluble metal plug is in the form of a generally cylindrical, externally threaded body having a front end and a rear end and being formed with an axial bore extending frontwardly from its rear end but terminating short of its front end to define an open rear end and a closed front end, the peripheral wall defining said bore having an annular zone of substantially reduced radial thickness between said rear and front ends; whereby, upon introduction of acid into said casing and said bore, the acid will rapidly eat away said annular zone for penetration of the acid externally of the plug to eat away the threads of said plugs.

2. The improvement of claim 1, wherein said plug is threadedly engaged with an interior thread in said sleeve whereby, upon introduction of acid into said casing and said bore, the acid will rapidly eat away said annular zone for penetration of the acid externally of the plug to eat away the threads of said plug interengaged with the threads of the associated sleeve; and wherein sealing means are inserted between said plug and the associated sleeve adjacent the rear end of said plug and forming an acid-resistant seal between the rear end of said plug and the associated sleeve.

3. The improvement of claim 2, wherein said sealing means comprises an O-ring lodged in an external peripheral groove formed in said plug body adjacent its rear end.

4. The improvement of claim 1, further comprising retaining means secured to the interior wall of said sleeve behind said plug to prevent movement of said plug into said sleeve.

5. The improvement of claim 4, wherein said retaining means is in the form of an inwardly projecting annular shoulder.

6. The improvement of claim 1, wherein a safety cap is secured to the end of the duct-forming device which is closest to the casing, said safety cap being substantially in alignment with the wall of the casing and located substantially within said machined casing hole and having a valve-controlled narrow passage which permits flow of fluid from the interior of the casing toward said plug but prevents fluid flow through the sleeve and into the interior of the casing, said safety cap at least partially being made of an acid-soluble metal.

7. The improvement of claim 6, wherein said acid-soluble portion of the safety cap is made from zinc.

8. The improvement of claim 6, wherein the flow through said passage is controlled by a ball check valve.

9. The improvement of claim 8, wherein the ball of said ball check valve is retained by a cage provided on the cap at a location facing said plug, said valve forming a bevelled seat surface adjacent said passage against which the ball is urged in sealing manner upon occurrence of fluid pressure in a direction toward said casing.

10. The improvement of claim 6, wherein said cap has a body portion of acid-resistant metal and a central portion of acid-soluble metal, said central portion containing said valve-controlled passage.

11. The improvement of claim 10, wherein said central portion is made of zinc.

12. The improvement of claim 10, wherein said acid-resistant body portion has an interiorly threaded flange portion for meshing with an exteriorly threaded end portion of said duct-forming device, whereby said cap can be screwed onto said threaded end portion.

13. The improvement of claim 10, wherein said acid-soluble central portion has an inwardly bevelled peripheral surface portion which engages a complementarily shaped surface portion of the acid-resistant body portion, whereby upon dissolution of the acid-soluble center portion, a substantially conical seat surface is formed on the body portion for receiving a ball sealed located within said casing.

14. The improvement of claim 10, wherein the flow through said passage is controlled by a ball check valve, the ball of said valve being retained by a cage located on the central portion at a location facing the plug, said cage including a flange portion on said central portion for retaining the ball.

15. The improvement of claim 10, wherein the diameter of said central portion is smaller than the diameter of said sleeve.

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JAMES A. LEPPINK, *Primary Examiner.*