An Analytical Study Of Subsurface Locking Mandrels

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INTRODUCTION

A historical review of subsurface locking mandrels reveals that there are 5 basic designs of subsurface locking devices available today. Conventional solid steel wireline methods are used to run and pull all the locking mandrels. All the designs are utilized to set flow controls in the tubing string and must meet the following requirements: (1) the locking mandrel must be accurately located in the tubing string in relation to the desired depth of the subsurface flow control; (2) the locking mandrel must be locked securely in place once the desired depth is located; and (3) the locking mandrel must effect a positive seal between the locking mandrel and the tubing wall.

In this analytical study each of the types will be reviewed with emphasis on the distinguishing features, advantages, and limitations of each particular locking mandrel. Particular emphasis will be placed upon a newly designed subsurface selective locking mandrel and its utilization in the completion and production of an example oil well from initial completion through artificial lift.

SUBSURFACE LOCKING MANDRELS

Throughout the oil industry subsurface locking devices are now used extensively to locate various flow controls in the tubing string. The economy and efficiency of these devices are taken for granted and the problems of automatically installing a locking mandrel in the tubing string thousands of feet below the surface are usually handled in a routine manner with a minimum of difficulty. The original design of the locking device to be run and retrieved under pressure is the serrated slip type locking mandrel. This slip type mandrel has been in use over 30 yr and was probably adapted from the hook-wall packer design. In all these years the slip type locking mandrels have changed little in their fundamental design.

The slip type locking mandrel (Figure 1) consists of a set of hook-wall serrated slips, a tapered expander mandrel, and some type of sealing element. As the locking mandrel is run into the tubing string on a standard string of wireline tools, the slips "float" on the mandrel until the tool reaches the desired depth. At this point, the slips are set in the tubing wall by proper manipulation of the wireline. The actual wireline setting is dependent on the particular slip type mandrel being installed. In the early designs cup seals were used and well fluids and pressures were utilized to expand the cups to the tubing wall to effect the seal. Later improvements used an expander mandrel to force the seal element against the tubing wall and effect a seal without depending on well fluids or pressure.

Although the slip type mandrel is used successfully to place flow controls in the well, the equipment's design and method of locating, locking, and sealing has certain inherent limitations that prevent it use in many wells, especially the higher pressure wells.

Setting and sealing effectiveness of a slip type locking device depends entirely upon the condition of the internal tubing wall. In wells where the tubing has been in the well for a length of time the tubing wall may not be suitable to effect proper sealing. Also, the radial force exerted by the slips is placed directly against the tubing wall and may tend to swell the tubing. Even with the tubing in good condition, most companies recommend limiting the use of the slip type locking device to wells where the pressure differential does not exceed 1500 psi.

Another problem that could be encountered with this tool is difficulty in retrieving the tool as desired. Because of the well pressure and corrosive action of the well fluid on the expander, the locking mandrel may be found to be "stuck" in the tubing and difficult to loosen so that it can be retrieved. Additionally,

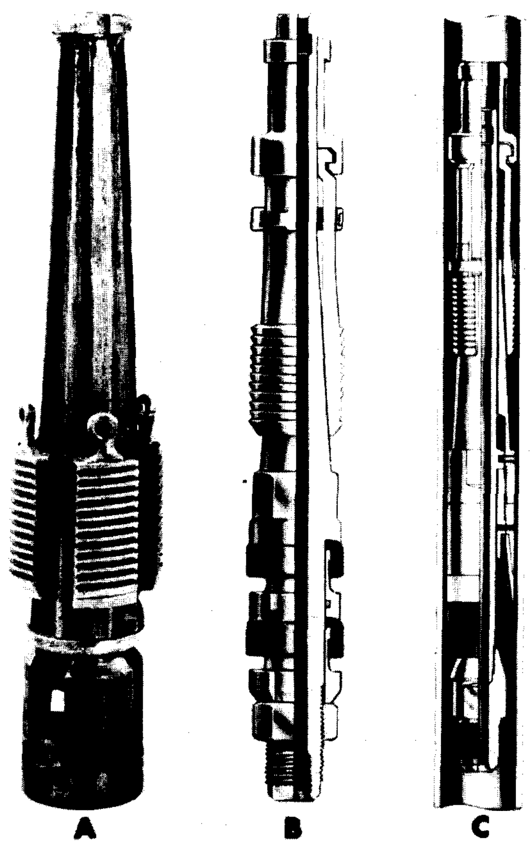


Fig. 1
Slip Type Locking Mandrels, Early Slip Type Mandrel (A); Current Designs For Slip Type Mandrels (B and C).

when they are to be retrieved, the cup seals are swollen to full size and the mandrel must be pulled with no clearance room between seals and tubing wall. A swabbing action will occur until the seals are worn enough to allow some clearance.

Since the slip type locking mandrel held a limited pressure differential in one direction only, the Industry expressed a need for a wireline retrievable locking device that would have an increased pressure rating and hold pressure from either direction.

One of the approaches taken to meet these requirements was to introduce a mandrel designed to locate and lock in the coupling recess of EUE tubing. The collar locking mandrel eliminated the use of serrated slips as the method of locking but retained the technique of effecting the seal against the tubing wall. The major improvement was the use of locking dogs that could expand only to a given or fixed diameter in the collar recess. When locked in a collar recess these dogs exerted load only against the end of the tubing joint. Since this location is the strongest point in the tubing string and the dogs are limited in their expansion, a minimum outward load is placed against the tubing wall. This lock plus a new type of 2 direction seal enabled the collar mandrel to withstand pressures from above or below.

Various designs of collar locking equipment are available and one of the more recent designs is shown in Figure 2. Although more complicated in design, the collar lock tool retains much of the mechanical make-up and action of the slip type mandrel.

The collar lock mandrel generally consists of locking dogs to engage the collar recess, some sort of dog carrier and a mechanically operated expander mandrel to expand the dogs and lock them in the expanded position and a seal element.

The operation of locating, setting and sealing the collar lock mandrel follows the slip type mandrel's procedure closely. The setting procedure for one of the collar-lock mandrels shown in Figure 2 is as follows: The entire locking dog assembly "floats" as the locking mandrel is lowered into the well. The equipment is lowered to a point below the desired collar recess and picked up. The locking dogs slide along the tubing wall until they encounter a collar recess. The dogs then expand into the collar recess and stop upward motion of the mandrel. Upward jarring is then used to move the mechanical locking mandrel behind the dogs and keep them in their outward position. Further upward jarring expands the two direction seal element.

Although this type of locking mandrel increased the pressure differential rating to as high as 5000 psi, again some limitations were apparent. Condition of the tubing wall was still a determining factor of whether an effective seal could be made and, on collar lock mandrels utilizing cup seals, of the problem of retrieving the locking mandrel remained a problem. The collar lock device in Figure 2 incorporates a pressure setting element that does away with the cup seal problems.

However, in premium threaded pipe there are no collar recesses and the collar lock type of locking device could not be used.

In answer to the needs left unfilled and requirements not met by the slip type lock and collar lock mandrels, the single recess landing nipple was developed. The landing nipples are installed in the tubing string to serve as specially prepared receivers for a nipple lock mandrel.

Several problems were solved by the single recess or "no-go" landing nipple (Figure 3). The landing nipple eliminated depending entirely upon the tubing as the locking area, extra strength could be built into the nipple to handle greater differential. Pressures could be held from above or below. Location was

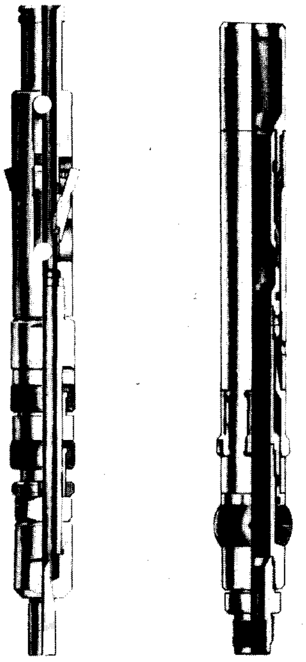


Fig. 2
Current Designs For Collar Locking Mandresls.

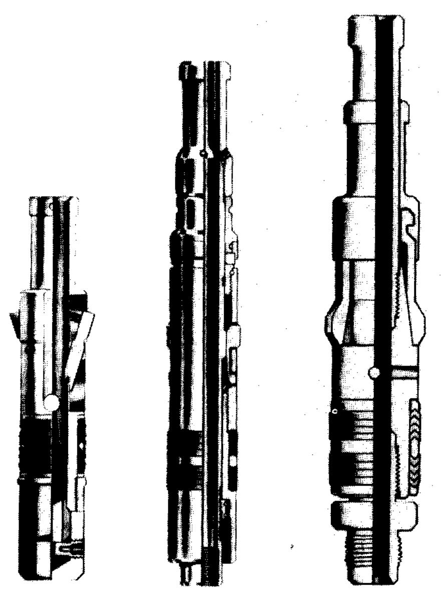


Fig. 3
Current Designs For Locking Mandrels To Be Used In Single Recess Nipples.

positive since the landing nipple was placed in the tubing string in the exact location where it was desired. Also, the landing nipple provides a honed packing bore and two direction vee-packing with a much higher pressure rating than cup seals or rubber elements.

As shown in Figure 3, the locking mandrel for the restrictive or "no-go" nipple is quite simple in construction. This tool incorporates a carrier mandrel, locking dogs, and 2 sets of vee-packing. The carrier mandrel is used to expand and lock the locking dogs into the recess of the nipple and not at any other point in the tubing string.

Pulling the mandrel is facilitated since the vee-type packing is slightly smaller than the drift diameter of the tubing and not as subject to swelling. All-in-all the single recess or "no-go" nipple paved the way for further improvements and more versatile subsurface locking mandrels.

The big limitation to the single recess nipple is its "no-go" feature. Location of the locking mandrel in the "no-go" landing nipple is simple: merely make a part of the locking mandrel larger than the "no-go" ring in the landing nipple. This locating method is limited since additional landing nipples in the tubing string require a further reduction of the tubing internal diameter and thus a tapered tubing string. Where production volume is of importance and a series of nipples are required to land more than one subsurface control, the "no-go" landing nipple again failed to meet all requirements.

For the wells that required more than 1 landing nipple, while retaining an essentially full opening tubing string, the answer was the development of the surface selective locking mandrel. This surface selective locking mandrel (Figure 4) and a series of landing nipples that incorporated the extra recess for locating purposes in addition to the locking recess allowed the desired flexibility. As many as 5 or 6 landing nipples

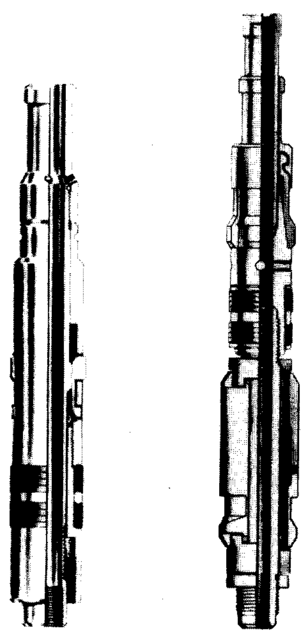


Fig. 4
Surface Selective Type Locking Mandrels For Use In Landing Nipples.

of this type could be incorporated into a single tubing string and retain the same tubing size. Selective locating of a specific nipple is accomplished by on the surface selection of the matching locator keys on the mechanically operated locking mandrels and by on the surface selection of the magnetic rings on the locking mandrel to match the magnetic rings of the landing nipple.

The development of surface selective locking mandrels and "selected keyed" landing nipples provided the best answer yet to the 3 major requirements of locking mandrels. The selective locator keys and the magnetic selectors will answer the accurate location of the locking mandrel. The utilization of vee-packing allows an effective seal inside the honed section of the landing nipple.

The many problems that originally confronted the locking mandrel designers were being solved. However, 1 limitation to the flexibility of both the mechanical locking and the magnetic locking mandrels is that the selection of the nipple for a landing point must be done on the surface prior to running the locking mandrel into the well. Once the tools are in the well, there is no changing of landing locations since the locator device is pre-set to locate in only the nipple with a matching recess or the matching magnetic key. If the pre-selected nipple could not be reached for any reason, a second wireline trip is necessary in order to set the desired flow control.

Both surface selective mandrels incorporate outside fishing necks and thus the internal bore of the locking mandrel is limited and this limits the bore of the attached flow control. In wells where large volumes are to be produced this reduced mandrel internal diameter was not desirable.

Even 5 or 6 landing locations provided by this type of nipple is not sufficient for some wells. Operators in many cases added a "no-go" nipple to the string in order to obtain another landing nipple location for safe and efficient production of the well.

These are minor limitations but are of extreme importance to the operator who is faced with overcoming the flow restrictions posed by the surface selective locking mandrel so back to the design board in search of a locking mandrel containing the advantages of the surface selective locking mandrel and the companion nipple, but also removing the limitations.

This new locking mandrel was announced to the industry in late 1962. It embodies a new concept in locking mandrels and landing nipples and shows promise of meeting all of industries completion and production requirements. This system is best described as a subsurface selective locking mandrel that utilizes a universal landing nipple as shown in Figure 5. The nipple is universal in the sense that it has one single locking profile for all nipples. No special sequence or preparation of the nipples is required before running the nipples into the tubing string. The locating recess or profile necessary to the surface selective type locking mandrel is eliminated. All the other benefits obtained through a specially prepared receptacle for subsurface locking mandrels are retained -- that is, relatively full opening bore, honed surface for two directional packing, extra strength, etc. The simplicity of the nipple had an extra effect in that it permitted the well operator to utilize a landing nipple at a lower cost than was usually associated with selective type of equipment.

The subsurface selective locking mandrel is similar to a standard "no-go" type lock, except that

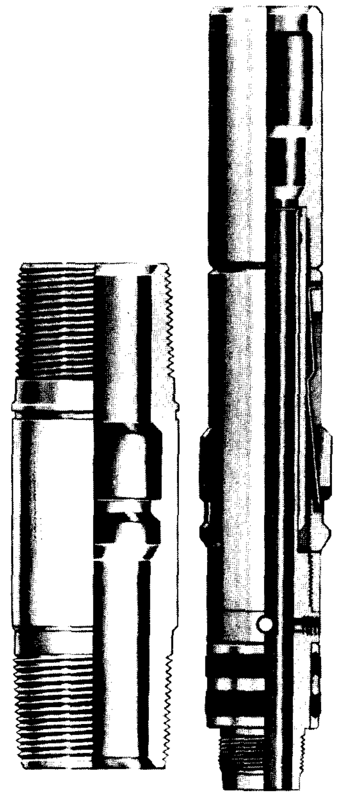


Fig. 5
New Subsurface Selective Locking Mandrel And Landing Nipple.

a "no-go" ring is not required. The locking mandrel consists of locking dogs, a packing mandrel with sealing elements, an expander mandrel and the necessary carrier for these components. The locating device is removed from the locking mandrel and is an integral part of the running tool. This type of design eliminated the necessity of the pre-selection of a specific setting location on the surface. For the first time we are discussing a locking mandrel that is controlled by the wireline specialist and any nipple location may be picked before or after the running tools are below the Christmas Tree. This flexibility in picking landing locations as well conditions are determined while the tools are in the hole reduces the number of wireline trips on many jobs since no return trip to the surface for special preparation of the locking mandrel is necessary (Figure 6).

Well records are useful but are not necessary as a guide to the location of the landing nipples in the tubing string. As the locking mandrel goes down the tubing string, the wireline specialist can feel the vee-packing pass through the honed surface of the nipple. He may correlate this indication of the nipple with the well records and depth measurements to recognize the desired landing point. However, positive location of a locking mandrel in a nipple is accomplished primarily through the locating dogs on the running tool; the dogs are sized so they will pass through a nipple when going down the hole. When the specialist determines that the assembly is below the desired landing nipple, he picks up on the wireline tools and brings the locating dogs on the running tool back up against the honed section of the nipple. The locating dogs will not come back through the nipple until a minimum 200 lb pull is exerted. This action confirms the location of the landing nipple and correlates the landing nipple depth to the wireline measurements.

One other action is accomplished when the locking mandrel is pulled back through a nipple. The locking dogs of the locking mandrel heretofore have been fully retracted and held in this position by the action of a spring. When the locking mandrel is pulled back through the nipple; the spring reverses its leverage and throws the dogs out to their maximum diameter in order to engage the locking recess in the nipple.

The locking action is similar to other nipple locking mandrels for the expander mandrel is jarred or driven down behind the locking dogs for a positive 2 way lock against pressures from above or below. One advantage provided with this mandrel is the provision of serrated edges on the outside of the locking mandrel and the inside of the dogs. The angles of these threads are such that a pressure differential from below tends to make them hold tighter and the greater the pressure the greater their grip.

Just before the specialist jars downward to drive the inner mandrel behind the dogs he has an option. At this point, before jarring, the keys are expanded only by the spring, and if for some reason it would be desirable to move the locking mandrel and flow control up the hole to a higher nipple or come out of the hole completely without setting, he may do so. This flexibility is 1 of the major advantages of the

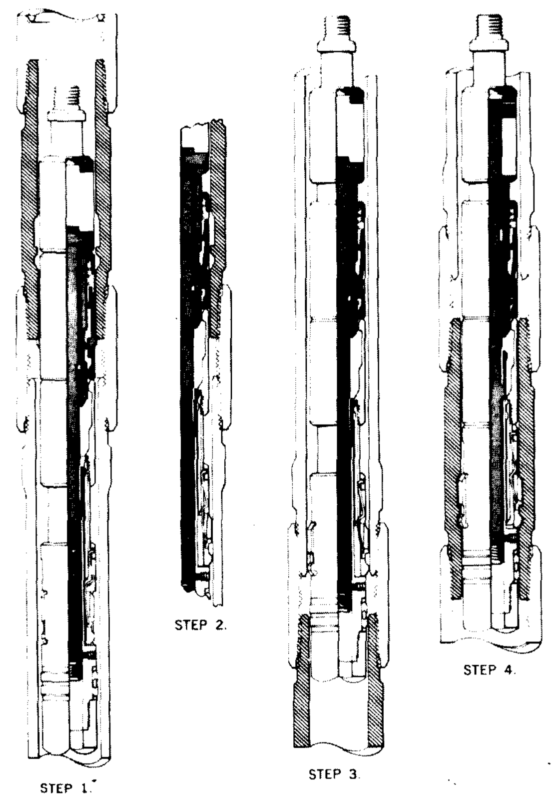


Fig. 6
Locating-Locking Procedure For Subsurface Selective Locking Mandrel.

subsurface selective mandrel for a wireline specialist maintains control at all times.

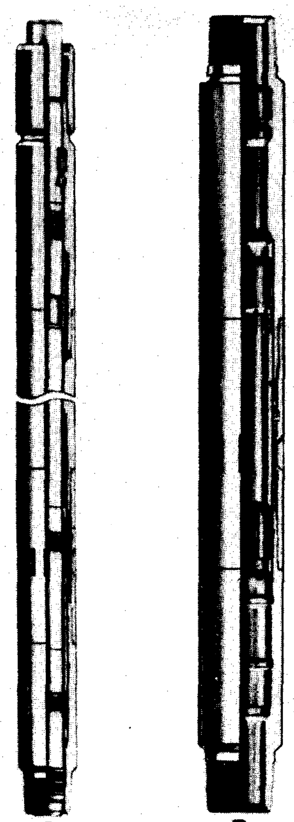
With a special running tool, the wireline specialist may progressively move the mandrel with a plug attached up the tubing and set in each nipple location. This procedure would simplify testing for tubing leaks, testing packer leaks, and isolating communication since only one wireline trip would be necessary for the entire string.

The locking mandrel also incorporates an inside fishing neck which allows a larger internal bore than is available with mandrels with external fishing necks. The larger bore permits greater flow volumes through the mandrel and flow control and lessens the pressure drop across the assembly.

With the internal type of fishing neck, sand bridging probabilities are reduced and thus the mandrel is easier to pull. Bailers can be run inside the mandrel and little room is left between the outside diameter of the fishing neck and the internal diameter of the tubing so that sanding up or well junk wedging the mandrel in place is unlikely.

The mandrel bore is of sufficient internal diameter that, depending upon the flow control attached, a a bottom hole pressure bomb or other wireline tools could be run through the larger size.

The many options available when running this equipment and the large bore of the mandrel adapt themselves into a complete line of completion and production equipment (Figure 7).



A B

Fig. 7
Tubing Incorporated Gas Lift Mandrel (A) And Sliding Side Door (R) (B) Utilizing Built-In Landing Nipple Recesses For Subsurface Selective Locking Mandrel.

The nipple, a heavy wall flow tube, a sliding side door and a honed packing section, when combined, offer a center set gas lift system. The large bore nipple is particularly useful when gas lift is considered.

This "line" or system of integrated equipment can open many doors to new completion and production techniques during the life of a well.

EXAMPLE WELL (FIGURE 8)

The flexibility and versatility of the subsurface selective mandrel is best shown on a well schematic. On this completion through artificial lift.

In our example, let's assume a well with the following date:

Depth - 7100 ft 2 in. Tubing in 5 1/2 in. casing
Bottom Hole Pressure - 3000 lb
Bottom Hole Pressure Decline - 400 lb 1 yr
Flowing Pressure - 500 lb
Production - 250 bbls
Initial GOR 650 - 1
Bottom Water at any time
750 lb Gas available to Kick off well and 700 lb Gas available to lift

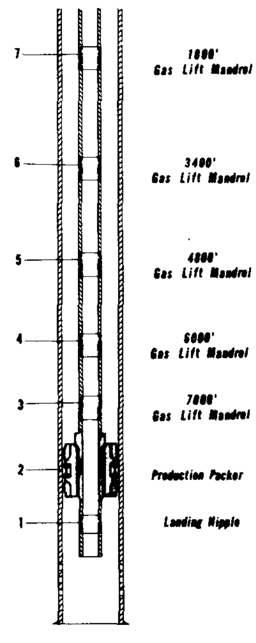


Fig. 8
Schematic Of Well Utilizing Subsurface Selective Locking Mandrel Landing Nipples And Allied Equipment.

This particular well will flow on initial completion, but will have to be placed on artificial lift within 2 yr after drilling. On the schematic we show the necessary subsurface equipment to accomplish the change-over from flowing to artificial lift. The equipment is used:

1. Landing Nipple: This nipple is installed below the Production Packer to be used to test the tubing or to seat a Plug Choke in the tubing string.

2. Production Packer: This packer is used to isolate the casing annulus above the packer from the formation.

3. Sub Surface Selective Mandrel Sliding Side Door: This Sliding Side Door is used above the Production Packer for circulation so that the well may be brought in with the Christmas Tree in place. Also the well may be killed with the Christmas Tree still in place.

4 - 7. Sub Surface Selective Gas Valve Mandrel Sliding Side Door: The Landing Nipple is used to land Flow Controls and Plug Chokes during the flowing life of the Well and to land Gas Valves during the artificial lift life of the well. Before running the Sliding Side Doors, by the use of the well data and the data from other wells in the field, it is calculated that for artificial lift that Gas Valves will be required as follows:

ft		lb
1800	-	700
3400	-	680
4800	-	660
6000	-	640
7000	-	620

After the well has been drilled and perforated, the Production Packer is run. When the tubing is run in the well the Sliding Side Door above the Production Packer is an open position. After the tubing engages the Packer or the Packer has been set, the tubing is landed in the Tubing Hanger and the Christmas Tree is installed. At this time the fluid in the tubing may be displaced into the Casing Annulus. Close the Sliding Side Door and the well is brought in, cleaned up and placed on production.

During the flowing life of the well, the following operations could be performed:

1. With a Test Tool in the bottom nipple, test the tubing.

2. With a Plug Choke in the bottom nipple, open Sliding Side Door to circulate fluid out of Casing Annulus with contaminating formation.

3. Circulate through any Sliding Side Door.

4. Land a Flow Control in any of the Sliding Side Doors to control well flow.

5. Land a Plug Choke in any of the Sliding Side Doors so that the Christmas Tree can be temporarily removed for inspection or replacement.

When it becomes necessary to place the well on Artificial Lift, all the work is accomplished with a wireline unit. Install a Plug Choke in the bottom nipple; open the Sliding Side Door above the Production Packer; and displace the mud out of the Casing Annulus. After the Plug Choke is pulled, the Sliding Side Doors are opened to furnish a passage for the injected gas from the Casing Annulus to the Tubing. All Gas Valves are calculated and properly set on the surface, and then the Gas Valves are installed in the proper Sliding Side Doors. As the gas is injected into the Casing Annulus, the Gas Valves will open and operate in the same manner as on a conventional Gas Valve Installation. If it becomes necessary to inspect at any of the Gas Valves, they are pulled on a wireline repaired or replaced and run back into the well.

CONCLUSION

Now that our historical review of subsurface locking mandrels has been completed it is concluded that:

1. On any type of well completion the type of locking mandrel depends on the application and the use.

2. At all times you should plan ahead on the initial completion to include the artificial life of the well.

3. The completion should be engineered so as to adapt to all future requirements.