IMPROVEMENTS IN WAG INJECTION CONTROL EQUIPMENT SIMPLIFIES OPERATIONS AND IMPROVES RELIABILITY

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ABSTRACT

Multiple-zone CO_2 water-alternating (WAG) injection techniques have changed little over the years and have relied on side-pocket-mandrel/injection-valve technology to accomplish an injection fluid diversion into targeted zones. These systems depend upon mechanical injection valves to disperse the injected fluid.

A new technique that both simplifies the process and provides increased reliability by eliminating mechanically operated injection valves has been introduced to the oilfield. Side-pocket-mandrel injection-control assemblies have been replaced with new reservoir access mandrel systems. This paper will explore the application of this improved downhole technology for WAG injection control.

INTRODUCTION

Water and gas (WAG) injection has been used for many years as a means of increasing production in depleting fields. In many instances, one wellbore is used to accommodate injection into multiple zones. Single-zone wells have not presented complications since they normally do not require any downhole diversion method to regulate the injected fluid or gas other than a packer to isolate the wellbore above from possible corrosive fluids. Multiple-zone wells, however, require a means of regulating the volume of injected material into each intended zone.

The traditional method of accomplishing a regulated diversion of fluid or gas into more than one zone is the use of a downhole assembly consisting of multiple packers and side-pocket mandrels with flow regulators. The multiple packers serve to isolate the targeted zones, and the side-pocket mandrels are run in the tubing string between the packers. Flow regulators are either run in place in the side-pocket mandrels or installed with slickline tools after being calibrated to operate at the required opening/closing pressures.

Flow regulators commonly contain spring–actuated moving parts that require the use of o-rings to maintain fluid-path integrity. They can have complicated disassembly and maintenance procedures. Another aspect of their use in the side-pocket mandrels is the process of retrieval and installation with slickline. Since the flow regulator resides in a pocket adjacent to the mainbore of the mandrel, running and pulling tools must have the capability to orient themselves for work at an angle while inside the mandrel. While not complicated, this does require a more sophisticated assembly than is used in most slickline operations. As in any operation performed downhole, the more moving parts that are involved with the mechanism, the more chances there are for miss-runs that can result in costly down time.[1, 2]

HISTORICAL METHODS AND TOOL FEATURES

A common multiple-zone injection tool assembly contains one or more hydraulically set packers. This type of tool is usually set by applying pressure inside the tubing string to activate the setting and locking mechanisms. With side-pocket mandrels in the tubing string, a method is needed to impart pressure integrity to the injection string while performing the setting operation. In this case, “dummy” or “blank” regulators are installed to keep the injection path sealed. After the down-hole tools are set, slickline is used to remove the blanks and again to install functioning regulators. Here again, the more sophisticated slickline tool assembly must be employed.

Flow regulators can also be installed on the outside of special injection subs and run with the injection assembly. Permanently mounted in this way, the entire downhole assembly must be pulled when the regulators require servicing or orifice modification. This method is used only when the cost of removing the tubing string compares favorably to slickline costs. It should be noted that removing the downhole assembly commonly requires that all tools in the string be refurbished before they are re-installed. In multiple-zone wells, this procedure can greatly increase the cost involved in maintaining or modifying regulators that have been installed externally.

The shortcomings in the use of downhole regulators in general led to the development of a simpler, reliable, and cost-effective type of tool to use in the same application.[2]

TECHNIQUE USED IN TOOL DEPLOYMENT

The new system, the zonal-control reservoir-access mandrel system (ZCRAMS), provides the capability to control inflow or injection for any interval in a well. When run with isolation packers, the ZCRAMS mandrels provide a positive and reliable method to shut off well segments. The ZCRAMS system consists of two separate components. The first is the reservoir-access mandrel. It is run generally as part of the tubing string or liner and is used as the inflow point into the production tubing. The isolation sleeve can be installed or retrieved depending on whether the adjacent interval should be producing or shut off. The ZCRAMS employs a patented "crimp seal" technology, which provides a seamless mandrel while providing maximum ID through the isolation sleeve.[1] (**Figure 1**)

OPERATIONS

The ZCRAMS sleeve is generally pre-installed in the mandrel before it is run into the well. This allows for pressure setting of hydraulic-set packers or for pressure testing the tubing string during the completion. The isolation sleeves are then removed, and the mandrel is left open or the blanking sleeves are replaced with flow-control sleeves (chokes). If changes are required during the producing life of the well, the isolation sleeves can be pulled and replaced as needed. Each time the sleeves are pulled, the seals can be redressed.

The isolation sleeves use a positive positioning system to provide installation certainty. They are generally installed using wireline in vertical wells and can be installed using either coiled tubing or sucker rods in horizontal wells.[1]

WELL APPLICATIONS

1. Water shut-off
2. Gas shut-off
3. Production testing
4. Formation fracture isolation
5. Stimulation
6. Selective production or injection
7. Individual interval stimulation and clean up
8. Horizontal drawdown control

FEATURES UNIQUE TO THE NEWLY DEVELOPED TOOL ASSEMBLY

1. Positive positioning system
2. Large isolation sleeve ID
3. Collet hold down system
4. The ported mandrels have an integral profile to accommodate commonly sized slickline lock assemblies. This feature allows the operator to install pressure/temperature gauges at the location of the ported mandrel for evaluation purposes

INSTALLATION CAPABILITY WITH VARIOUS OPERATIONS SYSTEMS

1. Wireline
2. Coiled tubing
3. Sucker rod
4. Pump-down.

The tool assembly is available with sour service or premium service versions, depending on the application and well environment.[1] **Table 1** shows the available tool dimensions and sizes.

TOOL DESCRIPTION

Regulated injection can be accomplished with a system of ported mandrels and removable sleeves. This technology uses an older system, that although underused, has a proven history of success where applied. A short tool, called a ported mandrel, is installed in the tubing string between packers and usually below the lower-most packer in a multiple packer installation. Injection control is then accomplished by inserting sleeves that have the necessary orifice sizes into the mandrels.

As described earlier, there will be one or more hydraulically set tools in the typical multiple-packer installation. As with side-pocket mandrels, ported mandrels require a means to give pressure integrity to the tubing string while setting tools hydraulically. This is accomplished by running the ported mandrels with blank sleeves installed across the ports. After the tool string is installed in the wellbore, the blank sleeves are removed and replaced with sleeves having the needed orifice size.

Sleeves are installed and retrieved with much simpler slickline tools than those required to work in side-pocket mandrels. Running and/or pulling multiple sleeves in a string is possible, because the ported mandrels are designed with a specific sealbore and minimum I.D. Each successively lower ported mandrel in an assembly has a smaller minimum I.D. than the one above it. Thus, the sleeve for the lowest ported mandrel in an assembly (and the slickline running/pulling tool) will pass through the I.D. of all ported mandrels installed above it. Each sleeve in an assembly is designed to locate its respective ported mandrel. It will not pass through the no-go shoulder of that tool. **Figure 2** shows an internal sleeve and tool body.

There are no moving parts or o-rings in this system as compared to the flow regulator/side-pocket mandrel tools. Sleeves seal in their respective ported mandrels with a very reliable crimp seal technology.

Sleeves are held in place by a collet, integral to the sleeve, which corresponds to a groove in the upper end of the ported mandrel. Since the sleeve is pressure balanced, very little force is necessary to hold it in place. The removal of sleeves from mandrels is accomplished with upward jarring action, similar to removing a plug from a profile nipple.[1]

APPLICATION

Ported mandrel/injection sleeve installations can be used in water, gas, and WAG injection wells. Consideration during design must be given to factors such as (1) injection tubing dimensions, (2) packer and profile nipple internal diameters, (3) possible requirements for the passage of production logging tools through the injection sleeves, (4) temperature, (4) fluid/gas types and their corrosive properties, (5) desired surface injection pressures, (6) depth of installation, (7) formation pressures, (8) pressure drop across the intended orifice, and (9) a given formation's capability to accept injected fluid or gas.

Upon knowing the above parameters, appropriately sized sleeves and ported mandrels can be selected, and a determination can be made as to the proper metallurgy and crimp seal material. Depending on conditions, materials can vary from nickel-plated steel and nitrile seals to more exotic metals and elastomers.[1]

Using a web-based program that calculates and creates reports for various valves, chokes, regulators, and friction losses for jobs, calculations of the required single orifice size for each target zone is determined. That single orifice size is then divided and distributed across three locations, each 120 degrees apart, on the central shoulder of the injection sleeve. This location corresponds to the openings in the ported mandrel and spreads the injection flow around the entire area of the ported mandrel, serving to limit erosion during injection.

In all wellbore environments, no equipment can be expected to last forever when conditions for corrosion and erosion exist. Therefore, a portion of the tool-application planning on a ported mandrel/injection sleeve installation should include consideration of appropriate intervals to pull the sleeves for inspection. In the injection process and reservoir management, there normally will be periodic injection profile evaluations made to determine that the injection rates are still meeting the well's requirements for idealized injection distribution. During these inspections, there will be opportunities to evaluate the actual tool conditions. Without the profiles being available, a good starting point to determine this interval is to consider the length of time a given operator has been able to inject through the side-pocket mandrel/downhole regulator equipment before having to pull the tools for repairs. Pulling the injection sleeves after the same amount of time will give a good indication as to the longevity of the sleeves in that particular well. If the sleeves come out and exhibit no damage from the injection process, then the length of time that they can be left in the hole before re-inspection can be increased appropriately. In this way, a timely maintenance program can be established.[2] Experience has shown that the ported mandrel/injection sleeve design is very durable.[2]

CONCLUSIONS

Injection wells are a very important part of reservoir management in maintaining production levels in many mature oil and gas reservoirs. The proper equipment installation design can make a great impact on performance and profitability. The uses of ported mandrels and removable injection sleeves offer a very good alternative to side-pocket mandrels with flow regulators. A simple design with a minimum number of moving parts usually decreases the cost of an initial installation, and as a general rule, allows the tool system to remain in the hole longer between scheduled maintenance events. When it becomes necessary to remove injection sleeves from ported mandrels, the operation is simpler, and therefore, less likely to be problematic than that of removing and replacing flow regulators in side-pocket mandrels. With this concept, the theory that "simpler seems to be better" has been proven once again.
The capability to reduce a CO_2 breakthrough from an injector into offset producers is demonstrated in **Table 2** and **Figures 3, 4,** and **5**.

REFERENCES

1. *Halliburton Service Tools Manual*, Descriptions and Applications, Tools Technology
2. *Permian Basin Tools and Services Applications*, Team Data Base

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Table 1

Reservoir Access Mandrel System

Tubing OD		Sealbore		Bottom No-Go Min. Tool Mandrel ID (Bottom No-Go)	
in.	*mm*	in.	*mm*	in.	*mm*
1.900	**48.26**	**1.500**	**38.10**	**1.447**	**36.75**
2 1/16	**52.39**	**1.625**	**41.28**	**1.572**	**38.35**
2 3/8	**60.33**	**1.812**	**46.02**	**1.75**	**44.68**
		1.875	**47.63**	**1.822**	**46.28**
2 7/8	**73.03**	**2.250**	**57.15**	**2.197**	**55.80**
		2.312	**58.70**	**2.259**	**57.40**
3 1/2	**88.9**	**2.750**	**69.85**	**2.697**	**68.50**
		2.812	**71.40**	**2.759**	**70.08**
4	**101.6**	**3.125**	**79.40**	**3.072**	**78.00**
		3.312	**84.10**	**3.260**	**82.80**
4 1/2	**114.30**	**3.688**	**93.70**	**3.625**	**92.10**
		3.750	**95.30**	**3.700**	**94.00**
		3.812	**96.90**	**3.759**	**95.50**
5	**127.00**	**4.000**	**101.60**	**3.910**	**99.30**
		4.125	**104.80**	**4.035**	**102.50**
		4.312	**109.50**	**4.223**	**107.30**
5 1/2	**139.70**	**4.560**	**115.80**	**4.472**	**113.60**
		4.750	**120.60**	**4.660**	**118.40**
6 5/8	**168.20**	**5.250**	**133.40**	**5.150**	**130.80**
		5.500	**139.70**	**5.400**	**137.20**
7	**177.80**	**5.750**	**146.10**	**5.625**	**142.90**
		5.900	**149.86**	**5.800**	**147.32**
7 5/8	**193.60**	**6.125**	**155.60**	**6.000**	**152.40**

Table 2
Injection Data from Three Different Intervals on CO_2 WAG Injector

Injection Data From ODC 712			
Zone	**Date**	**Rate (Mscf/D)**	**Wellhead Pressure (psi)**
	8/21	230	780
F-Pay	8/22	623	808
	8/23	604	817
	8/24	599	823
	8/25	599	824
	8/26	598	827
	8/27	595	821
	8/28	600	823
	8/29	596	824
	8/30	534	827
M-Pay	8/31	431	819
	9/1	486	825
	9/2	483	827
	9/3	486	822
	9/4	482	815
	9/5	483	816
	9/6	488	811
	9/7	484	813
	9/8	277	800
	9/9	213	797
TZ	9/10	505	832
	9/11	504	829
	9/12	506	834
	9/13	507	832
	9/14	506	835
	9/15	504	835
	9/16	503	845
	9/17	507	854
	9/18	504	848
	9/19	505	849
	9/20	502	850

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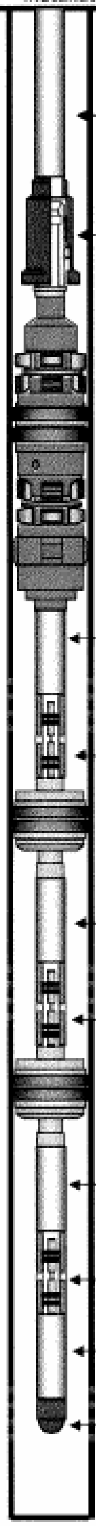
Proposed Installation



Installation	Length	Depth	Description	OD	ID
			INJECTION ASSEMBLY		
1			1.) 2-7/8 LINED INJECTION TUBING	2.875	2.140
2	2.33		2.) 7" XL ON-OFF TOOL 1.875" F STAINLESS GUDGEON & SEAL BODY XL Will Be 2 7/8" Box x 2 3/8" Pin	5.500	1.875
3	4.75		3.) 7" 23# G-6 Injection Packer plastic Coated G-6 Will Be 2 3/8" Box x 2 7/8" Pin	6.000	2.330
4			4.) 2-7/8 LINED INJECTION TUBING	2.875	2.140
5	1.50		5.) TOOL INJECTION CONTROL ASSEMBLY. 1.812" TOP NO-GO		SLEEVE 1.410
6	2.98		6.) 7 x 2-7/8 SPECIAL PKR. NACE w/HNBR NP OD / PC ID	6.000	2.330
7			7.) 2-7/8 LINED INJECTION TUBING	2.875	2.140
8	1.50		8.) TOOL INJECTION CONTROL ASSEMBLY. 1.812" BOTTOM NO-GO		SLEEVE 1.410
9	2.98		9.) 7 x 2-7/8 SPECIAL PKR. NACE w/HNBR NP OD / PC ID	6.000	2.330
10			10.) 2-7/8 LINED INJECTION TUBING	2.875	2.140
11	1.50		11.) TOOL INJECTION CONTROL ASSEMBLY. 1.625 BOTTOM NO-GO		SLEEVE 1.110
12			12.) 2-7/8 LINED TBG	2.875	2.140
13	0.5		13.) 2-7/8 BULL PLUG - Stainless Steel	3.668	

Figure 1 - Tool Diagram Showing Placement in CO_2 WAG Injection Well

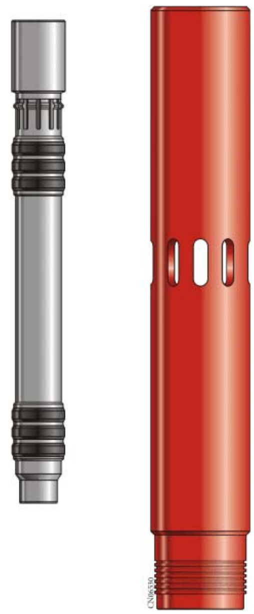


Figure 2 - Picture of Internal Sleeve and Tool Body

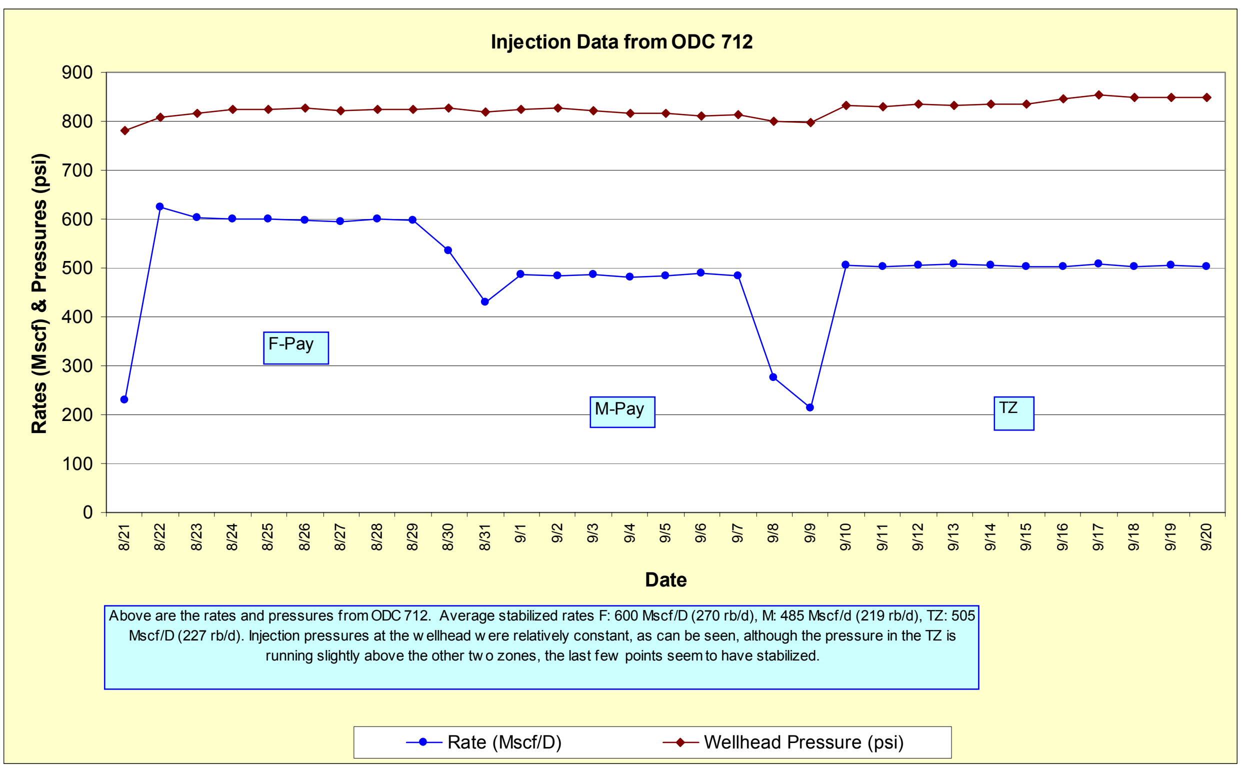


Figure 3 - Injection Data from Three Different Injection Intervals

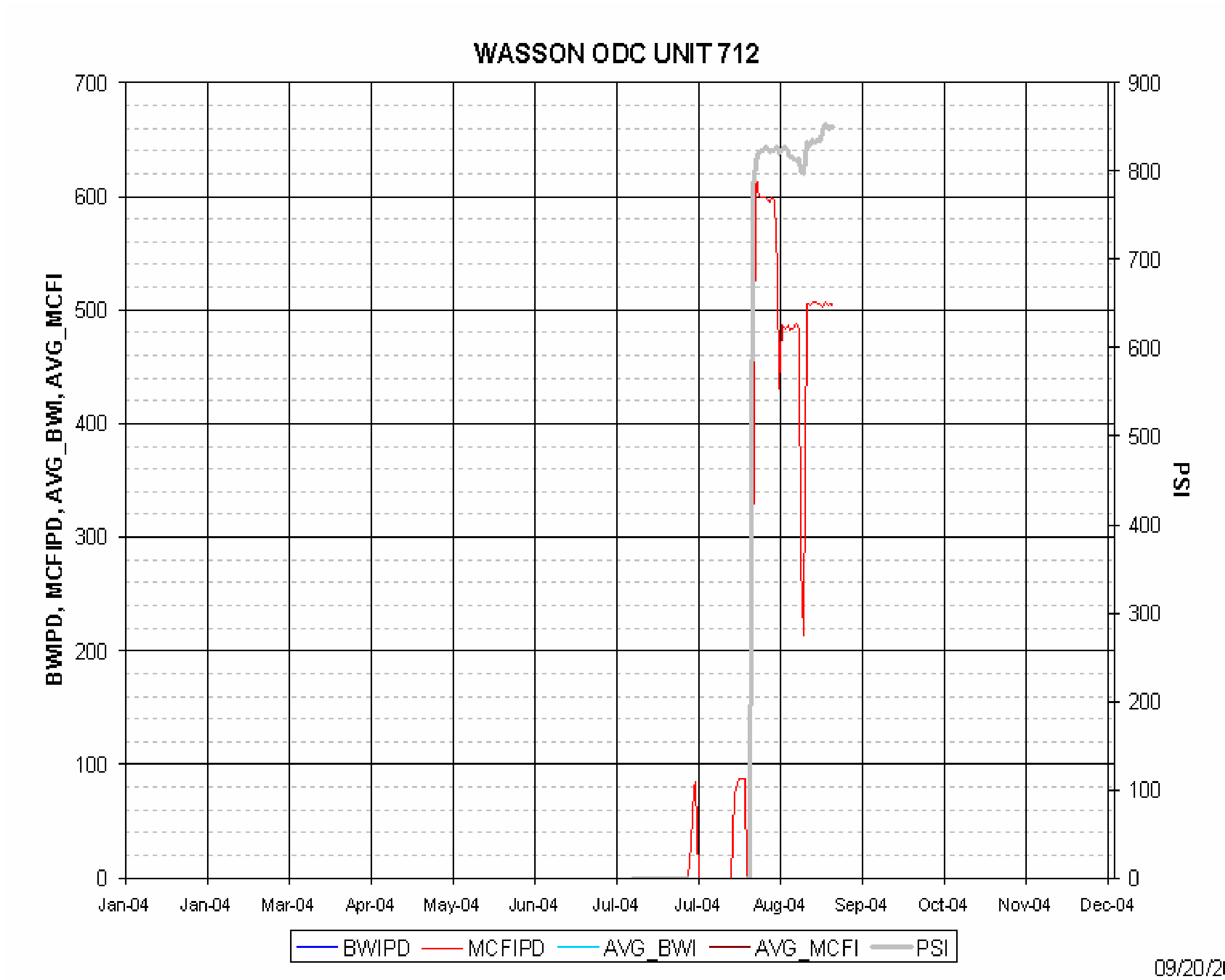


Figure 4 - Production Data - Offset Producers Showing CO_2 Breakthrough Prior to Running Tool

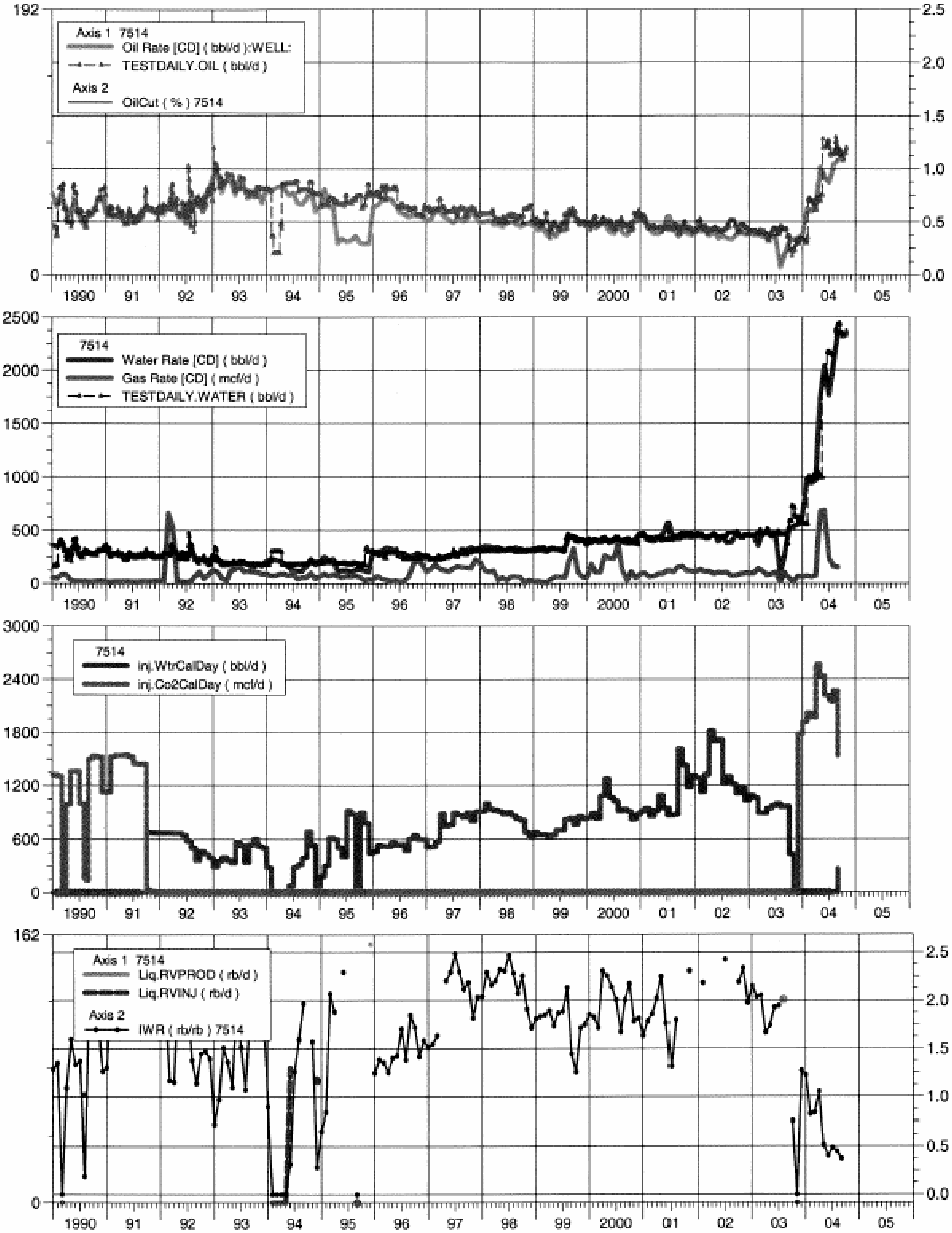


Figure 5 - Offset Production Modifications with Changes in Injection Intervals