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Argentina Tătaru*, Sándor Balázs*, Ion Foidaş*

UNDERBALANCED INTERVENTIONS IN GAS WELLS BELONGING TO MATURE GAS FIELDS

1. INTRODUCTION

Romgaz operates mainly in the mature natural gas fields located mostly in the Transylvanian Basin. These gas reservoirs are the largest gas producing reservoirs and their production represents over 65% of the total gas production. The majority of these fields were discovered and developed in the last century, from 1920 to 1970 and now they are part of rehabilitation projects. So, these reservoirs have over 80 years of production historical. Also, there are reservoirs or gas wells which are producing for over one century.

The initial reservoir pressures of these fields were aproximately 200–300 bar (2900–4350 psi), and their energetical reservoir potential were very high. But now, some of these reservoirs have dropped the pressure down to 10–20% of their initial values. Therefore in present it is very hard to make interventions in these wells conventionally.

These reservoirs are producing natural gas with elastic drive mechanism. Reservoir history matching show us that once these fields are put in production, the pressure is dropping irreversible. This phenomenon is called natural decline pressure curve (Fig. 1).

If at the early stage of reservoir exploitation, when the reservoir pressures and flow rates were considerable, it permited the intervention in these gas wells conventionally and working overbalanced, nowadays these type of interventions at higher pressures can lead to undesirable phenomenon as completion fluid invasion is near the wellbore zone. This thing can drop well productivity and can produce even well blocking (no flow).

Conventionally gas wells are drilled, cased and cemented using fluids with high density, $\rho > 1$ kg/m^3, which because of their weight generate a hydrostatical pressure higher than the pressure of porous-permeable media. This phenomenon is called overbalance.

* SNGN ROMGAZ SA, Romania

Working overbalance is a safety measure in these wells. This prevents technical accidents, like eruptions. But this safety measures must take in consideration the actual reservoir conditions not the initial one.

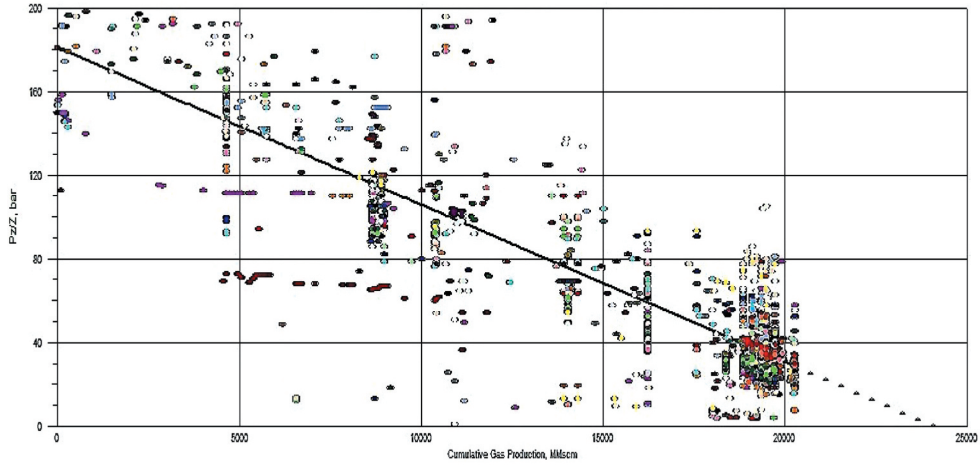


Fig. 1. Decline pressure curve for a natural gas field

Over the time there has been studied and tested the possibilities of avoiding and minimizing as much as possible the formation damage phenomenon due to reservoir contamination with various types of fluids in balanced or underbalanced conditions.

In the green fields the invasion phenomenon is not too accentuated and normally the wells could clean up from the undesirable fluid contamination in short time.

In mature gas fields allthough things look much different. Besides reservoir contamination there are presence of partial or total loses which can lead to formation damage. So, to avoid these situations, the state of the art technology offers solutions for every type of workover. If there are the need for completion fluids, these could contain bridging elements which can avoid or reduce reservoir losses.

Perforating operations are mostly made in balance or underbalance conditions, even with empty well, for avoiding salt water or completion fluids to flood the perforations.

Tubing handling can be done with well under pressure, so the perforated area is not possible to be damaged by various fluids types.

Taking this into account, the company specialists have to use the latest technologies applied to mature gas fields. So in many cases, the operations during workover are made at balance conditions taking in consideration the actual reservoir pressure and if it is necessary to kill the well. In this case to minimize productive layer contamination most often is used filtered reservoir salt water or completion fluid.

2. UNDERBALANCE INTERVENTIONS IN GAS WELLS

2.1. Coiled tubing

In the gas industry, coiled tubing refers to a very long metal pipe, normally 1 to 3.25 in (25–83 mm) in diameter which is supplied spooled on a large reel (Fig. 2). It is used for interventions in gas wells and sometimes as production tubing in depleted gas wells. Coiled tubing is often used to carry out operations similar to wirelining. The main benefits over wireline are the ability to pump chemicals through the coil and the ability to push it into the hole rather than relying on gravity. Pumping can be fairly self-contained, almost a closed system, since the tube is continuous instead of jointed pipe. For offshore operations, the “footprint” for a coiled tubing operation is generally larger than a wireline spread, which can limit the number of installations where coiled tubing can be performed and make the operation more costly.

The tool string at the bottom of the coil is often called the bottom hole assembly (BHA). It can range from something as simple as a jetting nozzle, for jobs involving pumping chemicals or cement through the coil, to a larger string of logging tools, depending on the operations.

Coiled tubing has also been used as a cheaper version of work-over operations. It is used to perform open hole drilling and milling operations. It can also be used to fracture the reservoir, a process where fluid is pressurised to thousands of psi on a specific point in a well to break the rock apart and allow the flow of product.

The most typical use for coiled tubing is circulation or deliquification. A hydrostatic head (a column of fluid in the well bore) may be inhibiting flow of formation fluids because of its weight (the well is said to have been killed). The safest (though not the cheapest) solution would be to attempt to circulate out the fluid, using a gas, frequently nitrogen (Often called a “Nitrogen Kick”). By running coiled tubing into the bottom of the hole and pumping in the gas, the kill fluid can be forced out to production. Circulating can also be used to clean out light debris, which may have accumulated in the hole. Coiled tubing umbilicals can convey hydraulic submersible pumps and jet pumps into wells. These pumps allow for inexpensive and noninvasive well cleanouts on low-pressure CBM (coal bed methane) gas wells. These umbilicals can also be run into deviated wells and horizontal laterals.

Underbalance and overbalance pressure conditions.

Where CT solids-cleanout services are performed to re-establish communication with an open completion interval, it is a common practice to underbalance the pressure within the annular fluid system relative to the bottomhole pressure. This minimizes the loss of circulated cleanout fluids to the formation and the damage associated with deposited solids. As the annular fluid velocities increase, the frictional pressure loss and equivalent hydrostatic pressure acting against the open formation correspondingly increase. If the formation is open to take fluids, then the volume of cleanout fluids returning to the surface decreases to a rate that maintains the proper balance of friction pressure and annular hydrostatic pressure acting on the open completion.

If the cleanout fluid was designed to hydrostatically balance the bottomhole completion pressure, then any additional pressure applied to the circulating system will cause an overbalance condition to occur. If the formation is highly permeable, then it is likely that a portion of the circulated cleanout fluids will be lost to the open completion once communication with the wash system is established. In effect, if the wellbore circulating system is balanced at a specific rate, the incremental increase in surface pump rate intended to increase circulation rates will most likely be diverted into the completion.

The rate of penetration of coiled tubing into a column of packed solids (wellbore cleanout) or drilled hole, coupled with a constant circulated fluid annular velocity, directly determines the concentration of solids captured within the cleanout fluid. The dispersion of the solids in the fluid media causes an increase in effective weight of the annular returns fluid. As a result, the hydrostatic pressure differential increases between the "clean" fluids pumped down the coiled tubing and the "dirty" fluids circulated up the annulus.

Fig. 2. Coiled tubing working scheme

2.2. Snubbing unit

Science people invented an equipment for tubing handling under pressure, in order to eliminate any productive layer contamination with different type of fluids. This equipment is called "snubbing unit" which can perform tubing handling without killing the well (Fig. 3).

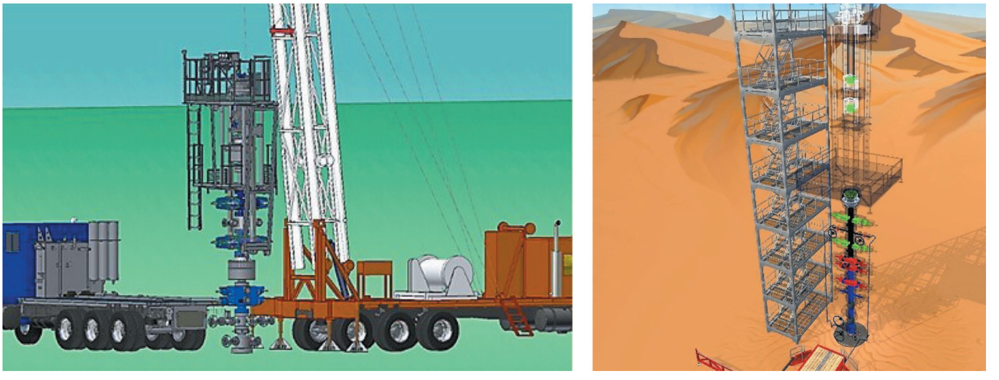


Fig. 3. Snubbing unit working scheme

The equipment is provided with a blowout preventer system which seals the tubing and a hydraulic system which permits lifting and lowering the tubing string in well.

Unfortunately this unit cannot perform the operation in wells with any type of wellhead. It can be used only on wells with API well head (oil type). The workover under pressure is not possible for non API well heads (gas type) because the tubing is screwed in tubing hanger so the wellhead must be lifted and rotated if the tubing must be lifted up.

Snubbing is the control of a tubing string while running it in or out of a well bore under pressure. This is accomplished by holding the tubing with inverted slips. One set of slips, stationary, holds the tubing while the other set traveling is used to force the tubing in or to hoist the tubing in a controlled manner; using cables and sheaves to allow the drawworks to control tubing movement. This method enabled the snubbing operation to be used as a self-contained modular unit.

The development of the hydraulic snubbing unit has expanded the horizons of the process tremendously; previously snubbing was considered "disaster services", as it was used as a last resort to get someone out of a terminal problem. The "disaster services" element is still evident but since the speed and efficiency of the hydraulic snubbing unit has been proven, it has been increasingly used as a production tool. The portability of the modular self-contained snubbing unit has also made it a viable workover/completion unit, in areas that previously would have been the domain of the service rig.

It is possible to develop a tremendous lifting power where a conventional workover unit would require structural changes and/or expensive transportation modifications.

The snubbing unit can perform the operation of repositioning the tubing in well (pull out from the perforated zone or run in the perforated zone), with the well still under pressure, by setting up a plug in tubing. After the tubing is out from the perforations zone it is possible to perform cased hole logging operations like PLT, thermometry or throughout tubing perforation jobs.

The snubbing unit can perform also the following operations: tubing pulling out of the hole, underbalance deep penetration perforation or casing logs as MIT, RBT.

After the desired operations are performed the snubbing unit is used to reinsert the tubing back into the well with the well under pressure and if is needed can be used to introduce tubing strings together with a packer which can be set up.

Romgaz performed all these operations with the snubbing unit in different situations.

So, there were performed the following operations like tubing repositioning like tubing run in hole for a better liquid unloading and tubing pulling out from the bottom of perforations zone to an upper zone for a better communication between top perforations and tubing.

3. CASE STUDIES

3.1. Coiled tubing operation

Coiled tubing operation on a specific gas well, that has a significant production history. This gas well has over 40 years of production and around 389 MMm^3 extraction cummulative. The reservoir static pressure at the moment of intervention was 35 bar, the depth of the well 2140 m.

The coiled tubind intervention working program, including well wash and nitrogen kick-off was the following.

The objective of the intervention is washing the interior of the tubing and the perforations, because after the dynamic reservoir measurement operation, the stencil stopped at 2101 m, the total tubing depth is 2130 m, the interior of the tubing is blocked so the well produces on the casing.

The gas well is equipped with slit pipes at 1640–2140 m = 500 m in total.

The wellbore schematic has the following scheme (Fig. 4).

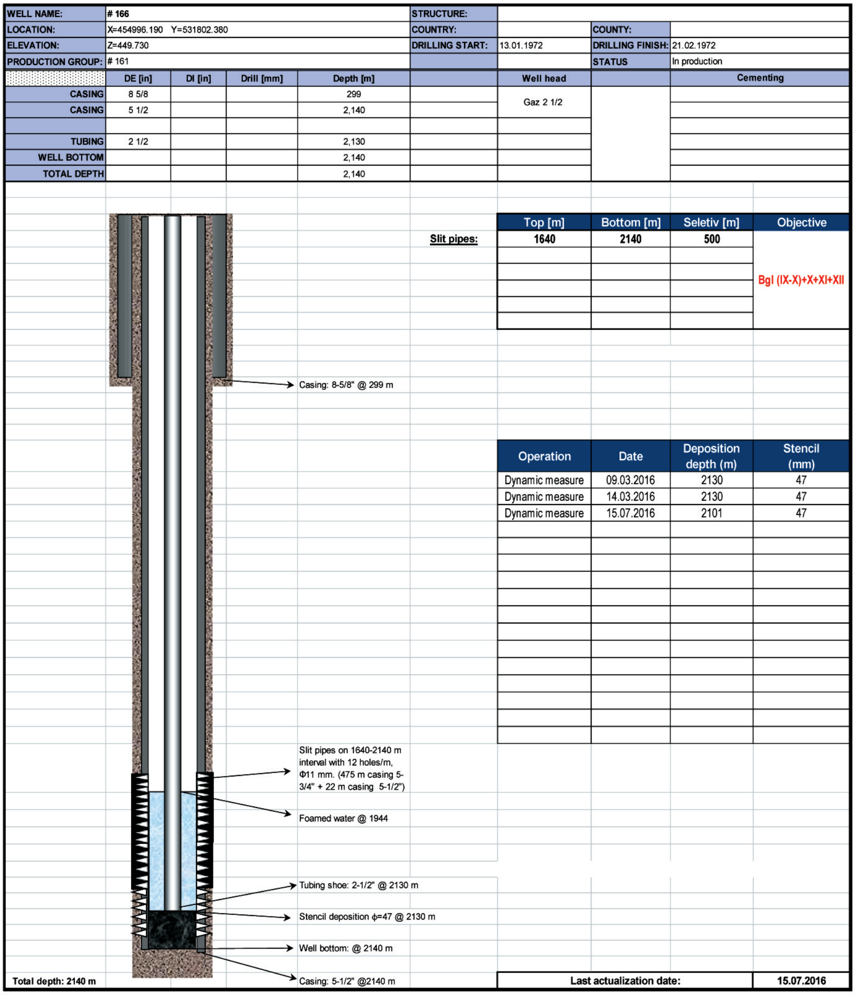


Fig. 4. Wellbore schematic before coiled tubing operation

Generally this type of operation is executed by following a few basic steps.

The valves on the tubing head will be opened. The coiled tubing will be introduced in the tubing from the surface, through the launcher (goose-neck) and preventer, equipped with the washing head which has frontal and sideways washing jets at 1800 m, advancing with 18–20 m/min or if it is necessary with another advancing velocity depending on the procedure, with 330 m above the tubing shoe and it will advance with nitrified salt water wash through the tubing up to the bottom of the well (Fig. 5).

The washing operation will start, pomping nitrified salt water into the well. The advancing velocity will be 10 m/min with a nitrogen pomping flow rate of 16 m^3/min down to 2000 m and continuing with an advancing velocity of 0.3 m/min and with a nitrogen pomping flow rate of 16 m^3/min and water pomping flow rate of 80 l/min down to the tubing shoe. Subsequently it will advance down to the bottom of the well with 0.3 m/min velocity, pomping about 2500 l of salt water.

Throughout this operation the pressure values will be monitored on the well head.

Fig. 5. Coiled tubing unit working on the field

Furthermore the perforations will be washed with nitrified salt water against impurities like rust and mud, performing two marches in 2130–2140 interval.

The introduced liquids in the well will be kicked-off using nitrogen. The nitrogen is inserted in the well through the coiled tubing and recovered in the annular space coiled tubing-tubing with a nitrogen flow rate of 16 m^3/min and after that through the annular space tubing-casing with a nitrogen flow rate of 35 m^3/min.

After this operation there will be introduced in the well two packages consisting of 700 l salt water and 200 m^3 of nitrogen. The coiled tubing will be extracted up to the tubing shoe and will be performed a final liquid kick-off using the remaining nitrogen, such that no liquids remain in the well.

The final nitrogen quantity includes the volumes to compensate the tank dead volume and the volumes used to accomplish the lines pressure samples.

Over the operation it will be taken in consideration that the hydrodinamic liquid column not to exceed the objective static pressure.

At the end the coiled tubing will be extracted and disassembled, the well will be closed for reservoir static pressure remaking (pressure value with 5 bar over the collecting field pressure or until the next day) and subsequently put back in production.

The extraction operator will monitor the well dynamic pressures and liquid impurities. After the operation the wellbore has the following schematic (Fig. 6).

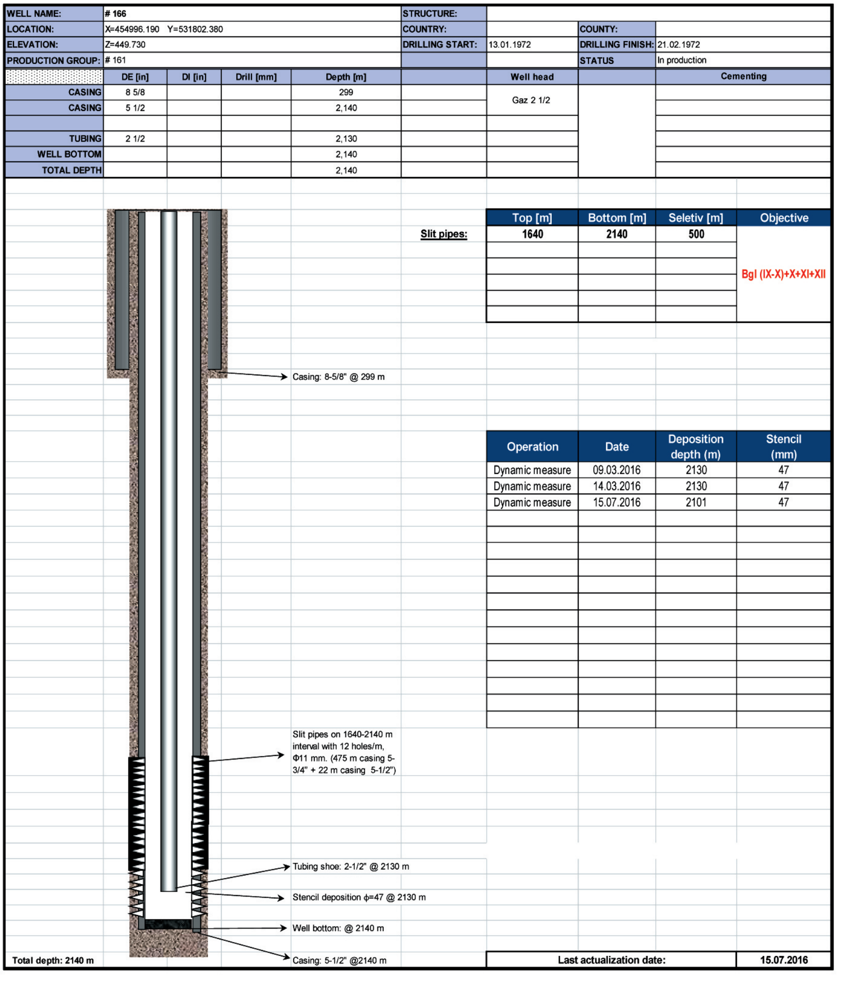


Fig. 6. Wellbore schematic after coiled tubing operation

Before the operation the studied well was exploited through the casing, because the tubing was blocked by mud, the well flow rate was around 4.0 Mm^3/day without water production, because the well could not be suppressed. At the moment of intervention the well was closed for a week, after that put back in production with a flow rate of aproximately 5–6 Mm^3/day for a few days when the well cleaned itself. After that period the well flow rate started to improve and stabilised around 10–12 Mm^3/day and water production of 50–60 l salt water per day.

Well exploitation parameters before and after the operation are highlighted in the following diagram (Fig. 7).

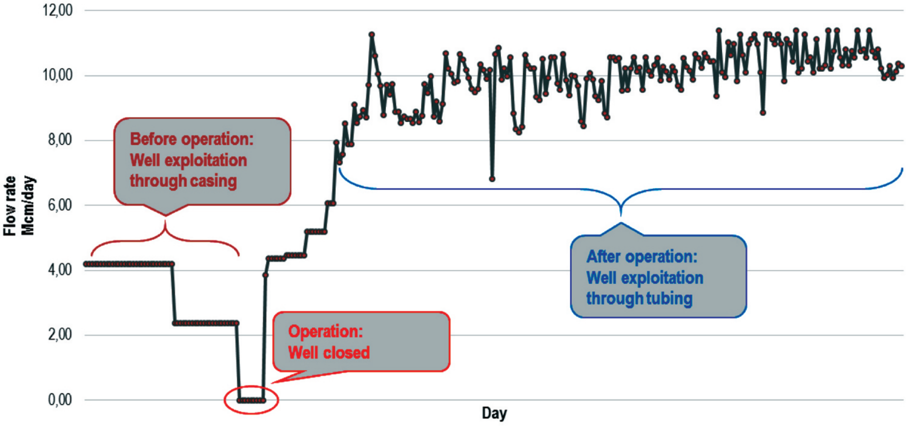


Fig. 7. Well flow rates before and after coiled tubing operation

Such good operation results were accomplished also on other few gas wells that exploited this production objective, with considerable flow rates that could match this well results.

3.2. Snubbing unit intervention

Another type of underbalance operation implemented on depleted gas wells are operation using the snubbing unit.

Snubbing unit operation on a specific gas well, with a significant production history. The gas well has over 40 years of production and around 100 MMm^3 extraction cummulative. The reservoir static pressure at the moment of intervention was 31 bar, the depth of the well 1180 m.

The purpose of this operation is the recompletion of the well for a more efficient liquid lifting from the bottom of the well. In this way, the tubing will be positioned on the upper part of the perforations without having to fill the well with liquids, thus not killing the well. At this time, the tubing is fixed by 1m below the base of the perforations, and the perforated interval has 102 m (90 m selective). The well accumulates water and is not able to lift up to the surface, because of the tubing positioning, lower than the bottom of the perforations. The foamed water accumulated in that area becomes more heavier over the time and the well energy is not able to "siphon" it anymore.

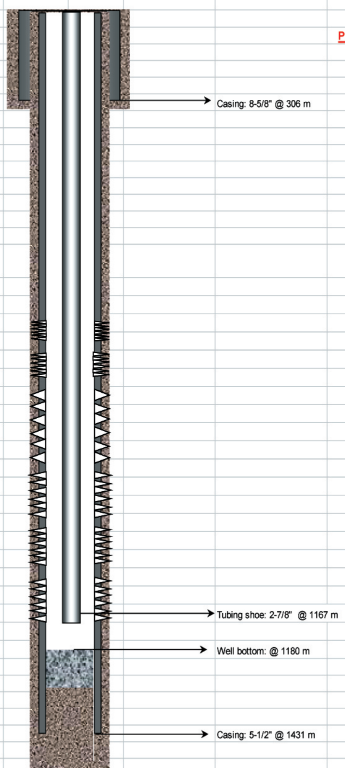
After the snubbing operation, there will be done a acidizing job on the perforations for reestablishing the layer-well communication.

At the time of the intervention the well flow rate was variable, depending on the water quantity that accumulated in it. The well is in production through tubing and also casing, because when it produces on tubing only the differences between the pressures on tubing and casing were very high. At the latest dynamic measuring, it has discovered that the well accumulates water (liquid level at 1100 m), and the stencil stopped at 1170 m (base of perforations). Also there was observed a periodic loading of the well which lead to reduction of production, and once the liquids are accumulated in the well they create a series of problems like clay inflation, layer backpressure and capilar force appearance.

The wellbore schematic before the operation is the following (Fig. 8).

WELL NAME:	# 71			STRUCTURE:			
LOCATION:	X=477070.74 Y=529478.060			COUNTRY:		Judeţ:	
ELEVATION:	Z=469.240			DRILLING START:	02.12.1976	Terminat foraj:	18.12.1976
PRODUCTION GROUP:	# 17					STATUS	In production

	DE [in]	DI [in]	Drill [mm]	Depth [m]		Well head		Cementing
CASING	8 5/8			306				La zi
CASING	5 1/2			1.431		Petrol 2 1/2 x 140		La zi
				3,36				
TUBING	2 7/8			1.167				
WELL BOTTOM				1.180				
TOTAL DEPTH				1.446				



Perforations:

Top [m]	Bottom [m]	Selective [m]	Objective
1064	1072	8	VIII
1074	1084	10	VIII
1086	1110	24	VIII
1112	1130	18	VIII
1134	1148	14	VIII
1150	1166	16	VIII

Operation	Date	Deposition depth (m)	Stencil (mm)
Dynamic measure	08.09.1998	1172	32
Dynamic measure	07.10.2003	1164	32
Dynamic measure	22.10.2003	1164	32
Dynamic measure	12.10.2006	1168	32
Dynamic measure	12.10.2006	1163	59
Dynamic measure	14.11.2006	1164	32
Dynamic measure	29.08.2012	1164	32
Dynamic measure	25.01.2013	1180	32
Dynamic measure	23.06.2015	1000/1002	47/32
Dynamic measure	17.08.2016	32/59	1170/1163

Last actualization date:	20.08.2016

Fig. 8. Wellbore schematic before snubbing operation

The operation will follow a few basic steps, which will guarantee the safety of the operation. In the well it will be mounted a nut stopper in the tubing with the help of slickline or wireline equipment. The well will be put in production through the casing so that the dynamic reservoir pressure not to build up very much.

The upper part of the well head and also the brace will be dismounted and a 6" valve will be rigged up. The connecting flange to the brace of the well head will be armored using a blind flange of 2–9/16". After that the snubbing unit will be rigged up.

The tubing hanger will be extracted up to the surface once with the first tubing. The tubing hanger will be fixed in the tubing head and the fixation nuts will be fastened. There will be extracted 9 pieces of tubing in total (Fig. 9).

Fig. 9. Snubbing unit working on the field

After all the tubing pieces are extracted from the well the snubbing unit and the 6" valve will be removed and the tubing head will be mounted back in position. The valves on the tubing head are handled so that the pressures vales in the tubing and casing to equalize, if the stopper is not provided with a pressure equalization device. The stopper is recovered and the well will be reinstated in production.

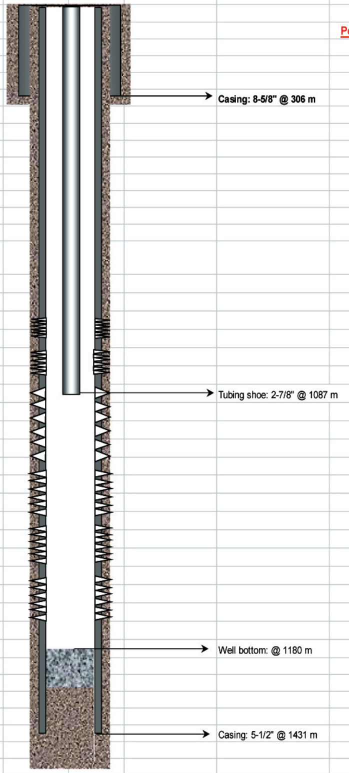
The wellbore schematic after the operation is the following (Fig. 10).

For this operation to be successfull, after the snubbing operation is finished it is in favor if the well is washed with the coiled tubing and after all the liquids are kicked off, it is best to effectuate a acidizing job to improve the productivity of the well.

For achieving this objective of productivity improvement, the perforated interval will be cleaned and the deposits that obstruct and worsen the flow in this area are dissolved. The chemical used for this operation is formic acid (28% concentration).

After the tubing is repositioned in the well and the perforations were washed, a nitrogen kick-off will be effectuated through CT-tubing with a nitrogen flow rate of 25 m^3/min, and CT-casing with nitrogen flow rate of 30 m^3/min, for liquid recovery from the well. After that the coiled tubing will be retracted in the tubing shoe (1087 m).

WELL NAME:	# 71				STRUCTURE:			
LOCATION:	X=477070.74 Y=529478.060				COUNTRY:		Judeţ:	
ELEVATION:	Z=469.240				DRILLING START:	02.12.1976	Terminat foraj:	18.12.1976
PRODUCTION GROUP:	# 17						STATUS	In production
	DE [in]	DI [in]	Drill [mm]	Depth [m]		Well head		Cementing
CASING	8 5/8			306				La zi
CASING	5 1/2			1.431		Petrol 2 1/2 x 140		La zi
				3,36				
TUBING	2 7/8			1.088				
WELL BOTTOM				1.180				
TOTAL DEPTH				1.446				



Perforations:

Top [m]	Bottom [m]	Selective [m]	Objective
1064	1072	8	VIII
1074	1084	10	VIII
1086	1110	24	VIII
1112	1130	18	VIII
1134	1148	14	VIII
1150	1166	16	VIII

Operation	Date	Deposition depth (m)	Stencil (mm)
Dynamic measure	08.09.1998	1172	32
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Dynamic measure	12.10.2006	1163	59
Dynamic measure	14.11.2006	1164	32
Dynamic measure	29.08.2012	1164	32
Dynamic measure	25.01.2013	1180	32
Dynamic measure	23.06.2015	1000/1002	47/32
Dynamic measure	17.08.2016	32/59	1170/1163
Snubbing 30.08.2016			
Dynamic measure	16.03.2017	1178	32/47

Last actualization date: 20.03.2017

Fig. 10. Wellbore schematic after snubbing operation

The acid solution is prepared in the pomping aggregate tank, using 1000 l of formic acid (28%) and 500 l fresh water. The water will be introduced first in the tank, after that the formic acid. This whole volume of acid, 1500 l, is introduced in the well advancing with the coiled tubing until the bottom part of the perforations and after that returning to the tubing shoe. Throughout the acid solution pumping operation, the well will be opened on the casing.

The coiled tubing will be withdrawn at a safety depth (900 m), the casing valve will be closed and the acid solution is left for reaction for 6 hours time. Throughout this time the well head pressure will be monitored, and in case it increases over 5 bar, it will be leaked, for not creating a overgrown pressure that favorize the acid solution permeation into the layer.

The valves on the tubing will be opened and it will advance with the coiled tubing down to the deposit, after what it will be executed a final kick-off coiled tubing – tubing with nitrogen flow rate of 25 m^3/min and coiled tubing – casing with nitrogen flow rate of 30 m^3/min for liquid recovery from the well.

When only nitrogen is observed at the surface, the coiled tubing will be extracted and dismounted.

Finally the well will be put back in production through the tubing

Well exploitation parameters before and after the operation are highlighted in the following diagram (Fig. 11).

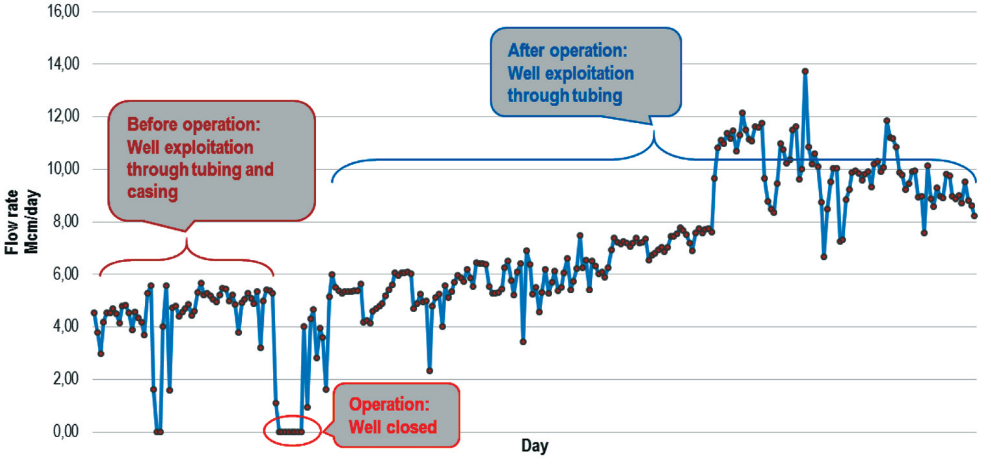

Fig. 11. Well flow rates before and after snubbing operation

4. CONCLUSIONS

In Transylvanian Basin are several major mature reservoirs. In these fields is better to apply the technology of underbalance well interventions instead of the traditional operations to avoid formation damage and to improve flow conditions as much as possible.

Especially in mature fields it is preferable to perform the underbalance interventions because compare to a traditional workover it takes less times for the well to clean up.

Even if a this type of intervention generally involves high costs it is also capital because only in this way we can work underbalanced in mature gas wells and the chances for the operation to be successful are very high.

Learning from our experience performing these types of operations in mature gas fields, we suggest to run a dynamic measurement tool before a coiled tubing or snubbing job, in the wells where this operations are possible.

As we have seen, performing coiled tubing or snubbing operations does not present major risks for well abandonment. In most cases, these type of operations ends beeing successful, helps clean out the wells or makes possible working under pressure and finally maintain or even increases the well production.

While the initial development of coiled tubing or snubbing was spurred by the desire to work on live wellbores, speed and economy have emerged as key advantages for application of coiled tubing and also snubbing unit. In addition, the relatively small footprint and short rig-up time make operations even more attractive for mature gas well applications.

Using this technology the wellbore is isolated from undesired flow of water (water influx) which can be easily controlled.

In the future, we will continue in the rehabilitation process of mature gas reservoirs to do underbalance interventions in gas wells. The biggest advantage of this kind of interventions is that we can optimize the production rates, minimizing the formation damage and maximizing recovery factor and reserves exploitation.

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