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Piston Effect and Ballooning in Horizontal SAS Completions: Challenges Encountered During Completion Integrity Test Operations

[1] Nnaemeka Ohia, [2] Charley Anyadiegwu, [3] Emmanuel MBA
Federal University of Technology, Owerri (FUTO)

ABSTRACT

This paper highlights the theories of piston effect and ballooning and how they can impact on the success of a completions integrity test. Piston effect caused by pressure changes induced during integrity tests in a tubing string stabbed into a packer bore can cause a reduction in the length of the tubing string. Internal pressure applied to the tubing string in the course of an integrity test can balloon the tubing string also causing a reduction in effective length. The results from this study have clearly shown that the combined effect of piston and ballooning can unseat the tubing seals from the packer bore leading to an unsuccessful integrity test. This was the case here and the (NPT) non productive time cost of this failure was over 450,000 dollars.

The well cited in this study is a horizontal oil well completed with a specialized stand alone screen (SAS) capable of providing both sand control and inflow control, aimed at delaying water and gas conning, thereby optimizing production in open-hole horizontal completions. Unlike other conventional sand screen designs, this sand screen achieves inflow control by means of nozzles/inflow control devices located in the screen housing and swell packers used to achieve compartmentalization in cases of non-uniform permeability. However, these nozzles can be plugged by debris from wellbore fluids during deployment and can act as a pseudo-closed system during integrity tests thereby giving rise to substantial piston effect.

This sand screen technology is relatively new and the well in this study is the second well to be completed with this sand screen design in the region. Ab-initio, conventional tubing/completion design philosophies practiced in the Niger Delta region consider piston effect and ballooning only as it affects tubing movement during production and not during deployment/installation. Going forward, these effects should be considered in the deployment program. This study has provided procedural recommendations on ways to forestall integrity test failures due to these effects.

Keywords: *Integrity test; ballooning; piston effects; Inflow control devices; standalone sand screens.*

1. INTRODUCTION

The well under review is located in the coastal swamp of Niger Delta, 40 km southwest of Port Harcourt, Nigeria. It is a field that has been producing oil since 1971. It is a horizontal oil rim development well with a production potential of 2000bopd.

Sand exclusion was recommended for this well by the field development team and also supported by the historical performance of other wells in this field. A stand alone screen was planned to be deployed across the 900 feet horizontal drain hole for sand control. The sand screen technology deployed comprised of standalone sand screens with inflow control devices (ICDs) for regulating flow from different sections of the drain hole to minimize heel to toe effect and the influence of variable permeability. Swellable elastomers were deployed in tandem with the screens to divide the drain hole into sections. The nozzle configuration was designed and optimized with the actual well results prior to deployment. This sand control design was expected to sufficiently retain the formation sand and forestall fines production in order to prolong screen life and minimize or eliminate remedial sand control related intervention in the future.

This sand screen technology also provides inflow control by equalizing the reservoir inflow along the entire length of the wellbore, hence functioning as a production management system by providing both sand control and flow control. Inflow control is achieved by means of ceramic nozzles which help to delay water and gas conning prevalent in oil rims, thereby increasing oil production.

2. MATERIALS AND METHODS

2.1 Well Design and Completion

The well was completed as a Single String Single (SSS) oil producer with 3-1/2” carbon steel tubing equipped with self equalizing TRSCSSSV and Permanent Down hole Gauge (PDHG) for well and reservoir surveillance. Four gas lift mandrels with dummies in place were installed with the upper completion string. The lower completion is a 4-1/2” screen which was installed as sand control mechanism across the 6” drain hole section, deployed with 4-1/2” blank pipe on a liner packer system and swell packers to isolate impermeable sections or shale sections. The well schematic can be seen in figure 1.

A hydro trip sub designed as a temporary tubing plug was installed in the tubing string to provide a means for pressure testing the tubing string (integrity test). This was achieved by dropping a 2.5” brass ball to a ball seat, which was expended after the test.

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2.2 Sand Screen Design

The sand screen technology deployed in this well as described is relatively new in the region. It is designed to optimize production from horizontal open hole completions by ensuring even reservoir influx and a uniform production profile along the entire producing interval, thereby delaying water or gas breakthrough. The screen design used is internally a blank pipe comprising of 2.5mmm ceramic nozzles that provide controlled pressure drop across the interval thereby ensuring uniform flow. It is externally covered with a 225 microns screen. Pressure drop across the nozzles is governed by the Bernoulli's equation:

$$\Delta P = \rho \frac{V^2}{2}, \quad V = \frac{q}{A} \tag{1}$$

Where:

ΔP = Pressure drop
q = flow rate
ρ = fluid density
A = cross sectional area
V = velocity

Pressure drop across the reservoir is equally governed by Darcy's equation:

$$\Delta P = q \frac{\mu L}{kA} \tag{2}$$

Where:

P = Pressure drop
L = length of well
q = flow rate
k = formation permeability
μ = fluid viscosity
A = cross sectional area

Pressure drop through a tube is affected by fluid viscosity but pressure drop through a nozzle is unaffected by fluid viscosity so flow control using nozzles gives better performance. However, pressure dissipation across nozzles is slower than pressure dissipation across conventional sand screens. And if the nozzles are plugged during deployment, pressure dissipation can even be much slower.

2.3 Upper Completion Integrity Test

Having deployed the lower completion (sand screens with a liner packer system and swell packers) to landing depth, the upper completion string was deployed with the tubing hanger. The tail of the tubing string comprising of a seal unit (6 feet long) was stabbed into the packer bore (liner packer of the lower completion) and located with a no go locator assembly, see figure 1. The seals were then picked up two feet from the packer bore, just before space out, in order to land the string in tension and accommodate possible tubing movement during production as per design. Hence the effective length of seals in the packer bore was 4 feet.

The tubing string was tested by means of an expendable ball-seat sub, to 3500psi, held for 15 minutes. Having obtained a good integrity test, the ball seat was to be sheared in order to restore a through bore. The shear pins of the hydro trip sub were rated to shear at 3800psi but failed to shear at that pressure. When pressured to 4000psi (which is above the margin of tolerance for brass shear pins), the ball seat did not shear. The ball seat eventually sheared after two pressure cycles of 4500psi but with flow observed through the 2" side outlet valve on the well head (outlet valve from the tubing-casing annulus or A-annulus). This valve was kept open during tubing string integrity tests so as to check for any flows, which may suggest a leakage in the tubing string.

The initial explanation was that one of the gas lift mandrels had failed thereby giving rise to communication between the tubing and the A-annulus hence resulting in the flow observed through the side outlet valve. Consequently a backside test was carried out on the A-annulus by applying 1000psi for 15mins and it held. Thereafter, with the side-outlet valves closed, the tubing string was picked up and an attempt to pressure up the string confirmed that the ball seat had sheared as pressure could not build up and a continuous flow through the flow line was observed. The tubing string was stabbed back again into the packer bore and with the side-outlet valve open, pressure applied in the tubing string with no flow observed through the side outlet valve.

The big question was, what caused the initial flow through the side outlet valve that gave the impression that the tubing string was leaking. and if this was the case, then it would have meant carrying out extensive leak investigation on the upper completion string or worse still pulling out the entire completion string. Careful analysis pointed in the direction of ballooning and piston effect as responsible for the flow observed through the side outlet valve.

The findings in this study have also supported the theory that 4500psi applied to a ball seat in an expendable ball-seat sub of a tubing string stabbed into a packer bore can generate substantial piston effect on the tubing string once the ball seat shears. This is possible especially if you have a closed system below the ball seat (as in this case of a specialized stand-alone sand screen), so once the ball seat sheared, the weakest link to the dissipation of the trapped pressure becomes the floating/unanchored tubing seals which can be unseated from the packer bore if the piston force is strong enough and if the seals are not long enough as was in this case (4feet)

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This pressure is also capable of ballooning the tubing string causing flow through the side outlet valve, especially for a large annular volume of556bbls.

3. RESULTS

3.1 Ballooning

If the pressure inside a tubing string is greater than the pressure in the annulus, the tubing string tends to swell or balloon. This ballooning force can be calculated using the following equation:

$$F_b = 0.6\,(\Delta P_t A_{ti} - \Delta P_{an} A_{to}) \qquad (3)$$

Where:

F_b= Ballooning force
ΔP_t= Change in tubing pressure
ΔP_{an} = Change in annular pressure
A_{ti}= cross sectional area of tubing ID
A_{to}= cross sectional area of tubing OD

$$F_b = 0.6\,(8{,}974.6 * 7.031 - 4{,}474.5 * 9.621)$$

F_b = 12,030 Ibs

This ballooning force produces a corresponding length change given by the equation:

$$\Delta L_b = 2.4exp - 8\left[L_t\left(\frac{\Delta P_t - F_{ol}^2 \Delta P_{an}}{F_{ol}^2 - 1}\right)\right] \qquad (4)$$

Where:

ΔL_b = Change in Length due to ballooning
L_t = Length of tubing string
ΔP_t = Change in tubing pressure
ΔP_{an} = Change in annular pressure
F_{ol}^2 = Ratio of tubing OD to ID

$$\Delta L_b = 2.4\,\mathrm{exp} - 8\left[11{,}946\left(\frac{8{,}974.5 - 1.17^2 * 4{,}474.5}{1.17^2 - 1}\right)\right]$$

ΔL_b = 2.24ft

3.2 Piston Effect

Pressure changes in a tubing string stabbed into a packer bore creates a piston force that acts on the steel cross sectional area. This piston force can be evaluated with the following equation:

$$F_p = (A_{pi} - A_{ti})\,\Delta P - (A_{pi} - A_{to})\,\Delta P_{an} \qquad (5)$$

Where:

F_p= Piston force
ΔP_t= Change in tubing pressure
ΔP_{an} = Change in annular pressure
A_{ti}= cross sectional area of tubing ID
A_{to}= cross sectional area of tubing OD

$$F_p = (12.57 - 7.031) * 8{,}974.6 - (12.57 - 9.621) * 4{,}474.5$$

F_p = 36,515Ibs

This force can produce an upward movement a corresponding to a length change given by the equation:

$$\Delta L_p = \frac{1.2 L_t}{\epsilon A_{tw}} * F_p \qquad (6)$$

ΔL_b = Change in Length
F_p= Piston force
A_{tw} = Cross sectional area of tubing wall
ϵ = Modulus of elasticity of steel (psi)

$$\Delta L_p = \frac{1.2 * 11{,}946}{30exp6 * 2.59} * 36{,}515$$

ΔL_p = 6.74ft

From the calculations, the combined forces due to piston effect and ballooning during the integrity test can result in a net reduction in the effective tubing string length of up to 8.98ft for the well under study. Hence unseating the seals momentarily from the packer bore since only 4 feet of seals were stabbed into the packer during the test. However once the pressure dissipates through the nozzles in the sand screen, the seals go back into the packer bore. This action can make an integrity test look bad thereby raising serious concerns and non

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productive time. This may even necessitate pulling out the entire tubing string.

4. DISCUSSIONS AND RECOMMENDATIONS

During the upper completions installation/testing with an expendable ball-seat sub, particularly in a case where it is designed to be stabbed into a "closed-in" lower completion scenario as described above, the following procedural recommendations are hereby highlighted below:

- Well completion programs should account for possible ballooning while testing tubing strings with large annular volumes.
- Possible piston effect while pressure testing tubing strings against the expendable ball-seat sub with seals stabbed into a packer bore must be calculated or simulated and provisions clearly made for it in the well program especially in "closed-in" lower ICD completion systems.
- Pressure tests of tubing strings should be done before landing the string with the tubing hanger profile or stabbing the tubing into a packer bore.
- This will prevent the exposure of the reservoir to string integrity test pressures.
- The tubing seals should be designed long enough to accommodate for possible piston effect and ballooning.
- Comprehensive quality assurance / quality control should be carried out on the shear pins of expendable ball-seat subs to confirm shear pressures under well conditions.

5. CONCLUSION

Typical tubing/completion design philosophies in most cases consider piston effect and ballooning only as it affects tubing movement during production and not during deployment/installation, especially as it relates to ICD systems. This paper has clearly shown these effects can be present during completion deployment operations/activities and must be accounted and planned for. This proactive approach can lead to a significant cost savings.

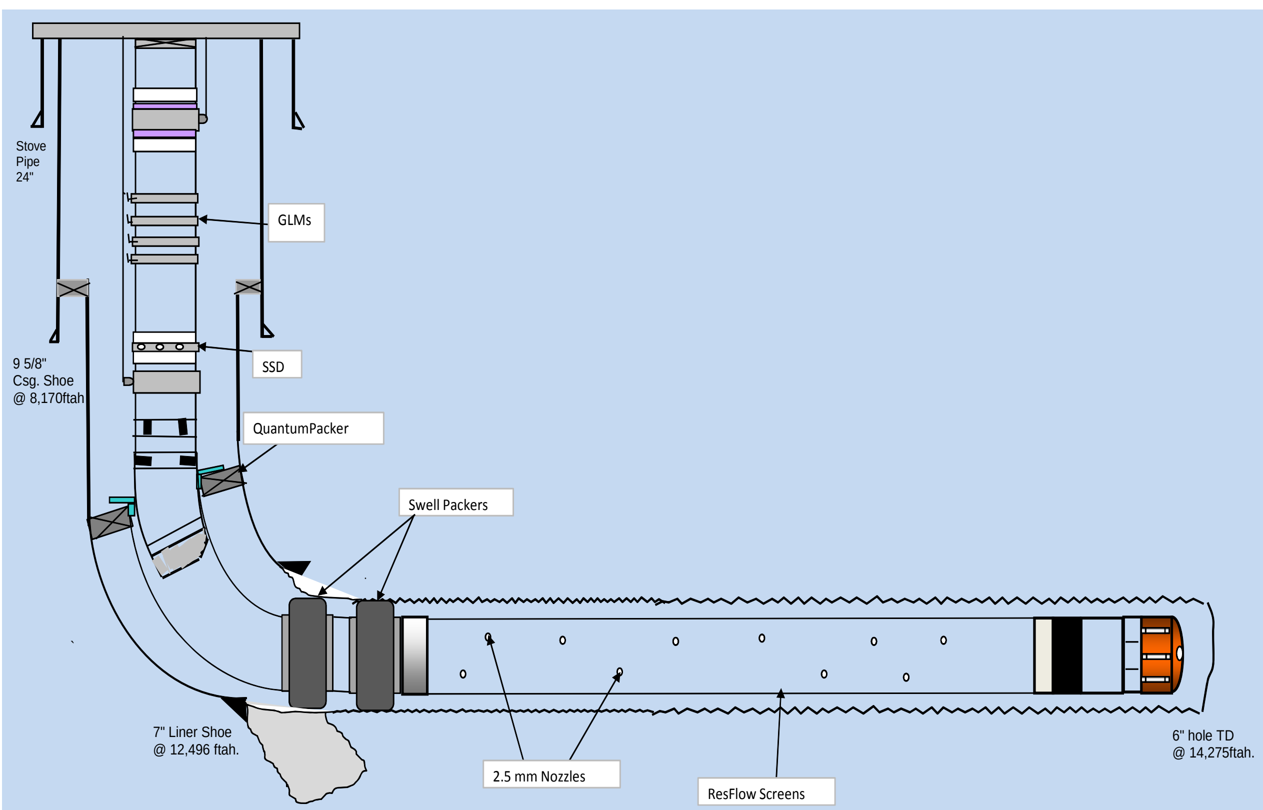

Fig 1: Well Completion schematic

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Table 1: Casing data

Hole Size (inches)	Casing Size (inches)	Grade/ Coupling	Weight (lbs/ft)	Interval (ftah)	Remarks
24	24	J55, WELD	186	402	Driven to Refusal
12-1/4	9-⅝	N-80, SLX	47	0 – 2,041	Cemented to surface with Class G cement
12-1/4	9-⅝	N-80, BTC	47	2,041 - 8170	Cemented to surface with Class G cement
8-1/2”	7”	N-80, SLX	29	7,021 – 12,496	Class G cement
6”	4-1/2”	N80, H521	12.6/ 11.6	12,496 – 14,275	12.6 ppf Blanks, Swell packer & 11.6 ppf Standalone Screens

Table 2: Tubing Data

Tubing OD (inches)	Tubing ID (Inches)	Tubing Length (ft, down to packer depth)	Tubing Wall thickness (inches)	Tubing Grade	Tubing weight (Ibs/ft)
3.5	2.992	11,946	0.508	N80	9.33

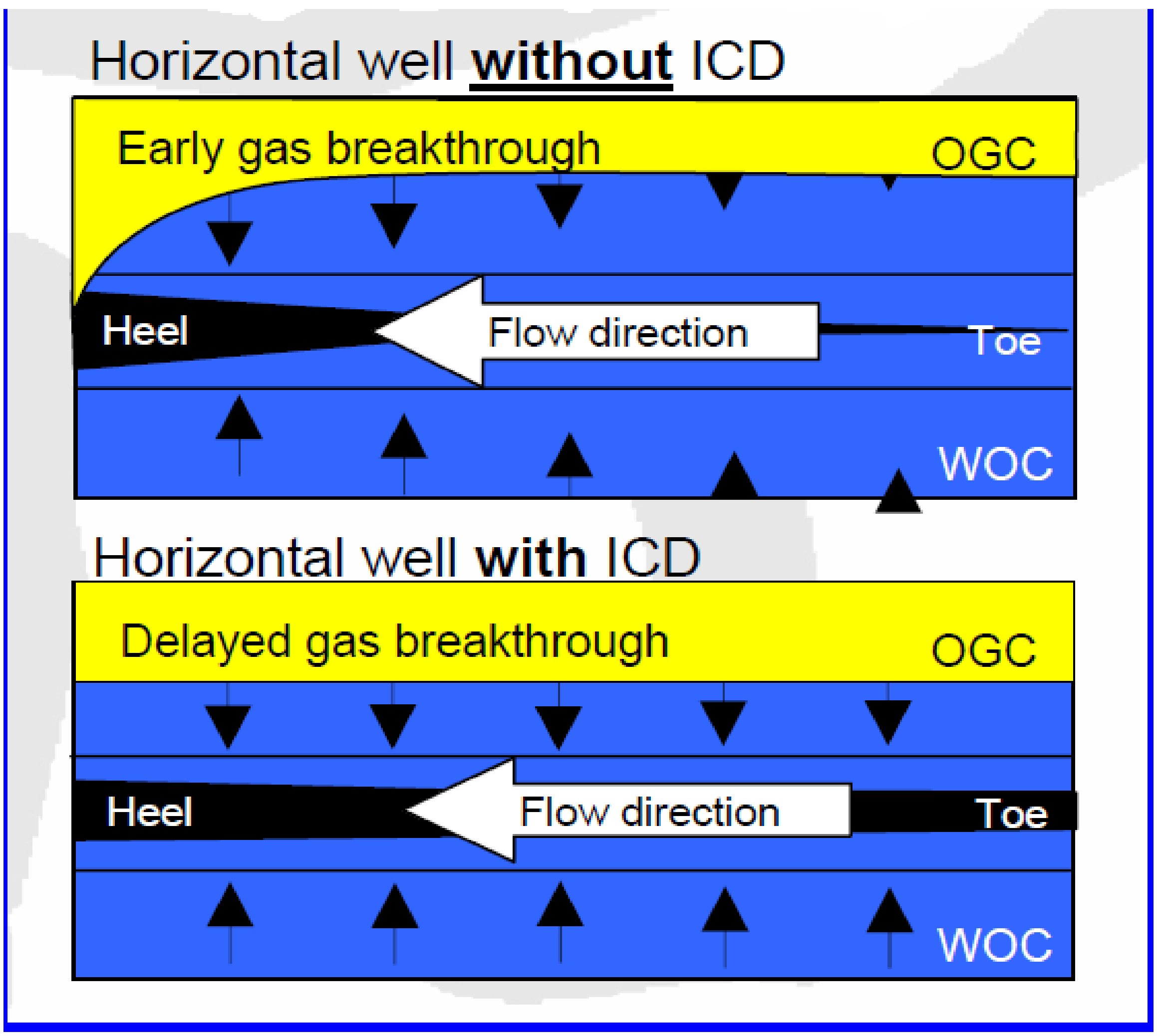

Fig 2: Inflow control illustration

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