CASING AND CEMENTING WITH POTENTIAL GAS INFLUX

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Summary

It is well known that wells should be reinforced by running the casing and cementing the annulus to create a competent cement sheath that helps to prevent the caving of the bore-hole. Other than supporting the casing, cementing the annulus also provides zonal isolation. The presence and migration of gas into the well annulus have been known as a problem in hydrocarbon exploration when complete isolation has not been achieved.

This report presents the general concept of gas migration in the well annulus and introduces some practical examples from experience of running casing and cementing in production and exploration wells in abnormally high pressure formations with substantial risks of gas migration in Vietsovpetro's fields.

Key words: *Well cementing, annular gas migration, phase transition period, hydrostatic pressure reduction of cement slurry column, preventative methods of gas influx.*

1. Introduction

Drilling wells create channels from a reservoir up to the surface. To produce oil and gas from the reservoir, one has to build sustainable channels that connect the reservoir to the surface and the storage tanks. For effectiveness and safety in the lift of oil and gas in the well from the reservoir to the surface, the wells have to be reinforced and all formations in the ground isolated. Only then, the wells can be competent for long-term production.

In casing and cementing jobs, steel pipes are thread-joined to form a casing string which is then lowered to the designed depth of the bore-hole. The process of dropping the casing string into the bore-hole is called running the casing. A cased well will be able to maintain the circular shape during drilling and production of oil and gas in the future. To anchor the casing string and isolate the reservoir, cement slurry is injected into the annulus. It displaces the drilling fluid, rises to the designed depth and sets to form a solid cement sheath. That process is called well cementing.

In fact, most of oil and gas production fields around the world have found traces of gas flow in the annulus after cementing and during production. Over a long time, this gas may migrate into another reservoir or up to the surface (Figure 1). In some cases, high pressure inside the cement sheath is created and becomes impossible to control, causing a blowout from the wellhead, which leads to tremendous damage both economically and environmentally [5, 7].

There are possibilities to greatly reduce the material costs and the time to overcome the problems above (the most serious is oil and gas blowout), if the source, causes and nature of the phenomenon of gas migration in channels through the cement sheath are clarified, and then there is timely application of the technical measures to prevent them.

This report discusses casing and cementing in an abnormally high pressure reservoir with a high risk of gas migration.

2. Fundamentals of gas influx and migration into the annulus

2.1. Practical consequences of gas influx and migration into the annulus

The annulus of a oil and gas well is defined (constructed and limited) by nested casing strings, borehole wall, casing head on the wellhead, cement sheath, and liquid column consisting of drilling mud, buffer fluid wash (in cases that cement slurry does not rise onto the surface) [3]. A cement sheath is formed only after the casing and cementing process is completed.

Gas intrusion and migration into the cement sheath in the annulus is a potential cause of several dangerous complications and occurrences. However, these are not always immediately detectable. The first indication of this phenomenon on the surface is the appearance and increase in pressure between casing strings or gas flow at the wellhead. Usually, remedial cementing is performed to force the cement into gas channels until the gas flow is stopped and casing pressure is reduced to a level compatible with the operator's safety policy and local regulations. However, the efficiency of squeeze cementing in such circumstances is very low for three essential reasons:

- Gas channels are difficult to locate, especially if they are less than 1mm in size;

- Gas channels may be too small to be effectively filled by cement;

- The pressure exerted during the squeeze job is sometimes sufficient to break the cement bond or even to initiate formation fracturing, creating problems in down-hole communication.

Gas migration between two or more subsurface zones, with no surface manifestations, is very difficult to detect (Figure 1). In such cases, gas production may be impaired; gas may migrate to an upper depleted zone (possibly followed by gas migration to the surface through another well), or the efficiency of stimulation treatments may be reduced.

Usually, cement repairing operations to fix the above problems are expensive, especially offshore or in remote locations. Therefore, preventing gas migration is definitely preferable to attempting to repair it [5].

There have been many subjective and objective causes in the oil spill disaster of Deepwater Horizon platform, offshore the Gulf of Mexico in April 2010. However, the investigation report indicated the main cause appears to be that the cement sheath did not maintain the isolation of oil and gas in the high-pressure reservoir, causing the gas to enter the annulus between casing strings and wellbore wall and then up to the wellhead [7].

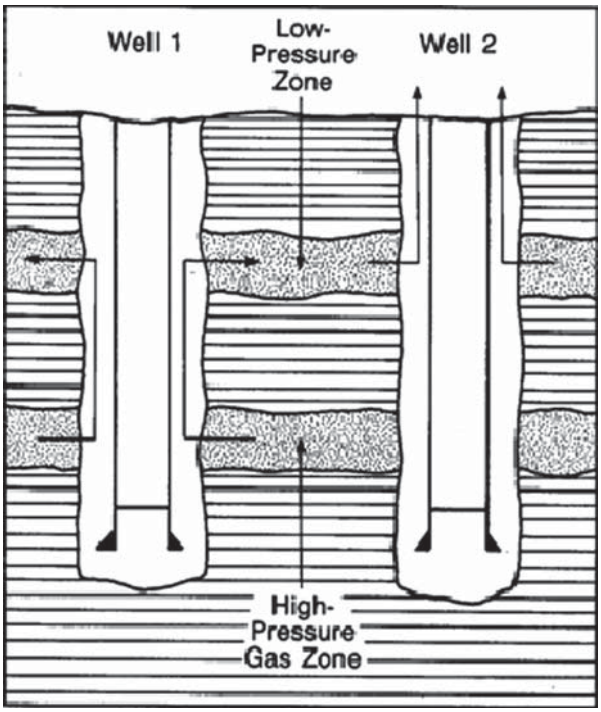


Figure 1. *Two scenarios for gas migration in the annulus*

2.2. Root causes for gas migration in the annulus

In principle, where there is a source (reservoir) of gas,annular gas migration has three distinct root causes:

- The hydrostatic pressure in the annulus falls to a level that is less than or equal to the pore pressure of a gas-bearing zone.

- Space in the annulus allows gas entry.

- A path is present in the annulus through which the gas can migrate.

2.3. Paths for gas migration in the annulus

Gas migration in a cement sheath requires paths. Gas migrates in the annulus between a cement sheath and casing strings, the cement sheath and wellbore wall, or directly through the cement. Some investigations state these three gas migration mechanisms, but also claim that it is impossible to use this concept to classify or indicate the gas intrusion phenomenon in any particular circumstance. There is almost no circumstance whereby only one mechanism took place.

2.4. Gas migration categories

Understanding and modeling the gas migration phenomenon is difficult because the conduit through which the gas can channel (i.e., an annular column full of cement, with possibly some spaces and drilling fluid left in the hole) evolves with times. The physical state of the cement progresses from a liquid slurry during placement to a permeable gel during a limited static period, then to a permeable-weak solid when setting, and finally to an impermeable solid after hardening. Therefore, the physical process of gas migration is conveniently categorised according to the timing of its occurrence during the cementing operation (Figure 2) [5].

2.4.1. Immediate gas migration (during the cementing process)

Gas intrusion during the cementing process occurs in the period from when cement pumping starts until the top plug is set on the bottom plug in the float collar. In this stage, gas migration into the cement slurry column is caused by the imbalance between hydrostatic pressure in the column and reservoir pressure. Preventing gas intrusion during this stage is similar to well control. The first method is to increase the drilling fluid density in the annulus. However, this method increases the risk of lost circulation or broken formation. The most reasonable method is annulus cleanout treatment before pumping cement.

Controlling gas migration while cementing is differentiated from well control in the drilling process via the phenomenon of gravity due to the "U-tube" effect. Due to the density difference between drilling fluid, buffer fluid and cement slurry, hydrostatic and hydrodynamic pressure of column fluid in the well always changes during pumping cement.

Sliding up and down casing strings will reduce hydrostatic pressure in the annulus when cementing due to the piston effect.

The fluctuation of cement density also causes gas intrusion during the cementing process. Inhomogeneous cement slurry develops the solid setting of cement slurry, free water...

2.4.2. Short-term gas migration (post placement gas migration)

This form of gas migration occurs between the end of the primary cementing operation (normally marked by the landing of the top wiper plug) and the setting of the cement (this time also is called as period of phase transition). Most of research suggests that the phase transition period of the cement slurry (waiting on cement) after cement placement is a dangerous time for gas intrusion. Thus the theory of gas migration and prevention methods often focus on this form [6]. The main reason for this is hydrostatic pressure reduction of the cement slurry column in the annulus after cement placement while cement is creating the structure and converting the phase from liquid to solid [2, 3, 4]. The reduction of pressure here is the combination of a variety of factors including free water, gel strength development and chemical shrinkage of cement hydration. It can also result from the formation of annular bridges or the setting of mechanical devices such as packers that isolate hydrostatic pressure transmission. Spaces for gas intrusion are generated by free water, chemical shrinkage and porosity of cement. At first, gas migrates through cement filter cake then through cement pores..

For the cement slurry as liquid and the cement rock as solid, there are many comprehensive methods for experimentation and study to determine their characteristics. However, the phase transition period between liquid and solid has not yet been fully investigated. Therefore, the gas intrusion phenomenon during this period is seen as the most complex form and is difficult to realise and forecast.

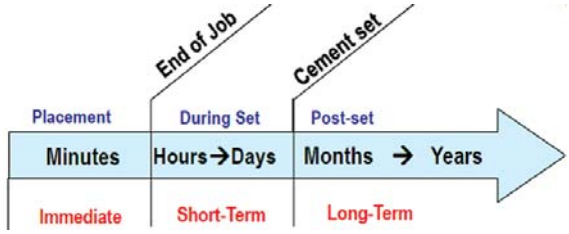


Figure 2. *Categories of gas migration*

The following formula is used to describe and estimate the value of pressure reduction:

$$\Delta P = \frac{4 \times L \times SGS}{D_h - D_p} \quad (1)$$

L: Length of the cement slurry column;

SGS: Static gel strength;

D_h (D_p): Hole diameter (casing diameter).

In fact, it is often assumed that cement begins to develop static gel strength at the time of cement slurry so as to allow itself to support its own weight. Meanwhile, the pressure between cement particles reduces to the equivalent of static hydraulic pressure. After this time, the cement slurry becomes solid and able to prevent normal gas intrusion. Therefore, for calculation simplicity, we can consider pressure at this moment as the lowest pressure values of cement column that can be achieved (i.e. ΔP achieves maximum). Then the following formula is used:

$$\Delta P_{max} = (\rho_{cem} - \rho_w) \times g \times L \quad (2)$$

ρ_{cem}: Cement slurry density;

ρ_w: Water density;

g: Gravitational coefficient.

2.4.3. Long-term gas migration

In recent years, a growing technical interest has been shown in the long-term form of gas migration due to the increased awareness of environmental protection. The reason for this is gas leakage into the environment from gas wells after their abandonment. The main cause of intrusion is the formation of gas channels after cement setting. After solidification, normal cement will become a low permeability solid (microdarcy). Gas cannot migrate through these pores, especially when it is saturated with water in the cement structure. A lightweight cement system (low density) containing a lot of water often has high permeability (0.5 - 5.0mD). Therefore, gas can migrate through the cement structure, although in small flows. However, over a long time, it can move onto the wellhead. This phenomenon can take a few weeks or months to reach the wellhead when sustained casing pressure in

the annulus appears and increases. Paths for gas influx after cement solidification are cracks, mud channels, channels caused by poor displacement of mud by cement slurry, channels due to cement dehydration, mud filter cake dehydration, or due to mechanical stress or temperature changes on the cement sheath in the annulus. The space that contains the gas is the chemical shrinkage, shrinkage of bulk cement, shrinkage due to channel liquid, and clay or mud filter cake dehydration. Due to cement solidification, at this stage the cement column does not transmit hydrostatic pressure to the gas reservoir.

3. Well casing and cementing with potential gas influx of Vietsovpetro's fields

3.1. Engineering geological conditions

Currently Vietsovpetro is producing oil mainly from three fields in the Cuu Long basin. They are Bach Ho, Rong and Gau Trang. Although there are various geological factors, they also have common characteristics, i.e.:

Source of gas with high reservoir energy in Vietsovpetro fields from Oligocene formations can influx or migrate into wells during drilling, casing, cementing and production.

The bore-holes in Oligocene formations are cased (reinforced) by running the liner or production casing strings in two types of well schemes (Figure 3).

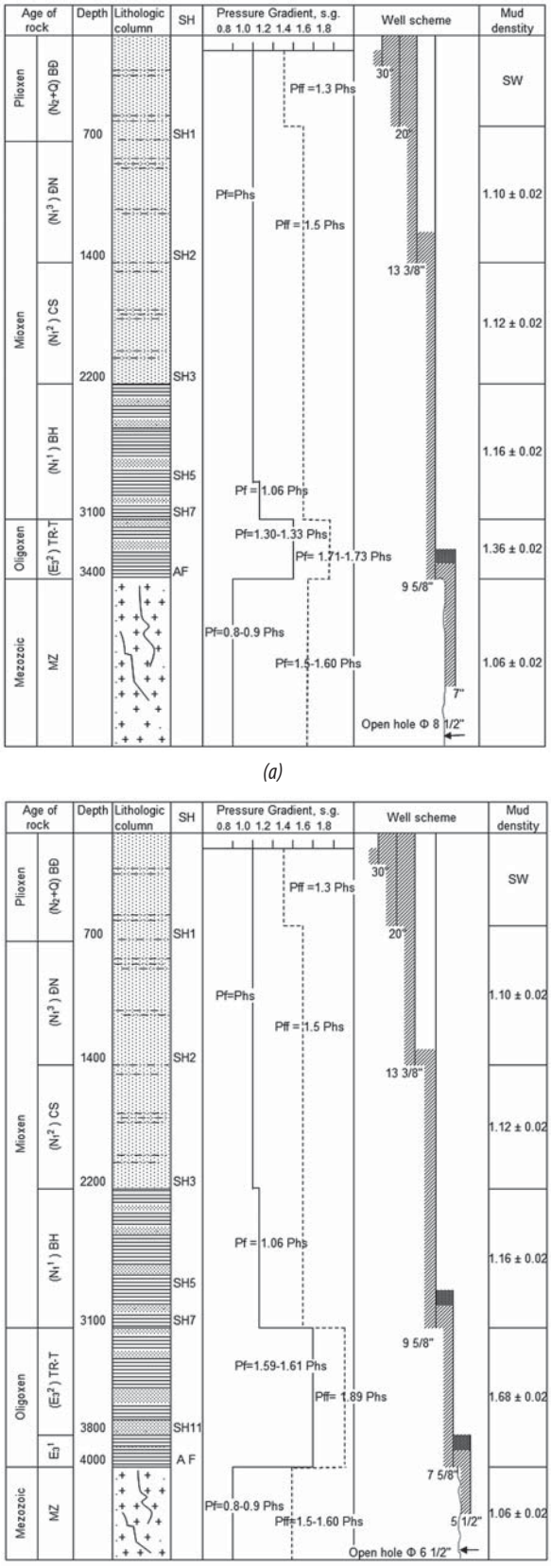
3.2. Reinforcement of wellbore though formations with gas migration risk by running the production (intermediate) casing onto the surface

For the location of the geological cross-section with not-too-high abnormal reservoir pressure in the Oligocene formation (up to 1.40), we could use the production casing string Ø 245mm to support the wellbore to the top of the basement. The wellbore in the Oligocene formation is drilled and cased (reinforced) with the wellbore in the Miocene formation by running one casing string and cementing (Figure 3a).

Gas migration risk factors include: (i) high pressure gas source from the Oligocene formation; (ii) cement slurry column length of approximately 2,000m being affected by the phenomenon of hydrostatic pressure reduction during the phase transition period. If using cement density of 1.53g/cm^3 for the 2,000m length, according to the formula number (2), the hydrostatic pressure may be decreased by:

$$\Delta P_{max} = 0.1 \times (1.53 - 1.0) \times 2{,}000 = 106 kg/cm^2$$

Measures to prevent gas migration can include the design of two types (lead and tail) of cement slurry that have different properties to minimise gas intrusion due to the hydraulic pressure reduction of the slurry column.



(a)

(b)

Figure 3. *Casing programs to reinforce the wellbore through formations with the risk of gas migration (a: by running the production (intermediate) casing to surface; b: by running the liner)*

As shown above, the cementing process in Vietsovpetro's fields almost never has any problem of gas migration. Gas can influx when cementing by using buffer fluid (cushion water) at the time when cement starts to flow out of the casing shoe, and then the pressure will be balanced when cement reaches the bottom hole and out of the casing shoe and goes up in the annulus. Gas influx into slurry can occur while pumping cement. However, before the end of the cementing process, gas does not reach the wellhead and hence it may not be seen at the surface.

Short-term gas migration after the cementing process of production (intermediate) casing strings in Vietsovpetro's fields has generally been controlled by two types of different cement properties (thickening and setting time) (Table 1). Essentially, when the above cement slurry column (first type-lead cement) is still liquid and transmits hydrostatic pressure to the gas reservoir, the type below (second-tail cement) covering the gas-source formation must set before that. In addition, the second type should have extra isolation properties compared to normal. This technique is simple and seems to work effectively for Vietsovpetro.

However, application of this technique failed in two cases, i.e. Well 440-BK-4 when cementing the casing Ø 245mm on Xakhalin rig and 20-DR RC-4 when cementing casing Ø 194mm on rig West Larissa. In these cases, casing design and cementing were the responsibility of other contractors.

3.3. Reinforcement of wellbore in high pressure formation by liner

When drilling through Oligocene formations with high abnormal formation pressure, heterogeneous conditions occur on drilling between Miocene and Oligocene formations. In this case wellbore through the Oligocene formation is reinforced by liner (Figure 3b).

In principle, the well is reinforced in abnormal high pressure conditions by running and cementing the liner, so the risk of gas migration due to hydrostatic pressure reduction of the cement slurry column in the phase transition period is very little. Because the cement slurry column length is short, there is always the drilling fluid column (its length is long when comparing with cement) that impacts on the top of cement. If the overlap distance between the liner top and the previous casing shoe is 200m and the cement density 1.73, the largest reduction value of the hydrostatic pressure exerting on the top of the Oligocene formation is calculated as:

$$\Delta P_{max} = 0.1 \times (1.73 - 1.0) \times 200 = 14 kg/cm^2$$

Thus value ΔP is very much smaller than the hydrostatic pressure of the drilling fluid column (length 3,000m) above the cement slurry column. If the drilling fluid density is 1.65, the column hydrostatic pressure is approximately:

$$P = 0.1 \times 1.65 \times 3,000 = 495 kg/cm^2$$

Measures to prevent gas intrusion when casing and cementing through high pressure formations by liner in Vietsovpetro are using packer on the top of the liner and keeping wellhead pressure after cement placement on WOC period. However, these measures appear to be ineffective.

According to the 2010 - 2011 Annual Report, there were many problems in the process of casing and cementing liner. Table 2 presents the level of success when casing and cementing liners [1] of Vietsovpetro's fields.

There are many possible reasons, but most failures are related to abnormal conditions of casing and cementing liner (before cementing and while cementing there was occurrence of both gas intrusion and loss circulation, cementing without return). The liner is sliding to the hole bottom after its hanging. The liner top packer is not sealed after primary cementing and so compels secondary cementing (squeeze job) to fill and seal completely or running an additional casing-liner linkup (tieback) above. The cost is therefore increased.

Thus, the principle of well reinforcement in formations with risk of gas intrusion by casing and cementing liner in Vietsovpetro (save the casing) can prevent the dangerous phase transition period if compared to running casing up to the surface. However, there are still many complicated problems. It is shown that existing techniques and technology of casing and cementing liner are incomplete, and not in accordance with the engineering geological conditions of the field.

Table 1. *Properties of cement slurry for production (intermediate) casing*

Interval (m)	Slurry density (g/cm³)	Spread of slurry (cm)	Thickening time (hours-mins)	Setting time (hours-mins)		Free water (%)	Bending strength (kg/cm²)
				start	finish		
3,457-1,106	1.53	25	7 - 10	10 - 35	11 - 10	1.5	24.6
3,957-3,457	1.57	21.5	5 - 05	8 - 50	9 - 35	0	26.5

Table 2. *Percentage of success (no complexity) when running and cementing liner (12/2010-12/2011) in Vietsovpetro's fields*

Diameter of liner (mm)	Number of times casing & cementing liner	Number of operation with complexity	Success rate (%)
194	14	8	43
178	6	3	50
140	9	3	70

4. Problems in prevention of long-term gas migration after cement setting

There are two types of gas migration, that during immediate and that after (short-term) the cementing process of casing strings, in which preventive measures (though simpler) were noted and applied. This is understandable because at this time the wells are still not complete and are in the process of drilling - building wells (wells have not been accepted, not yet put into production). If gas flow or fluid is detected in the annulus, it will have to be fixed/repaired immediately. This is the job of drilling team (contractors).

The phenomenon of gas migration after cement solidification (long-term) is often discovered long after the cementing, sometimes even months or years after the well has been put online. Then management responsibilities are no longer placed upon the drilling contractor. This is why works to prevent gas migration of the third type is unnoticed and seldom done in the well-construction process (in the cementing process).

Thus, from the process of running casing and cementing in formations with a high risk of gas migration in Vietsovpetro's fields, we also realise that during the drilling process, we do not have any measures to prevent long-term gas migration after cement solidification.

5. Conclusion

- Practice and theory have confirmed that the presence, intrusion and migration of gas in the annulus are a particularly complex problem which is difficult to fix and repair and may lead to serious consequences when it happens. Therefore prevention before this occurs is the most practical and economic measure.

- In Vietsovpetro's fields, reinforcement of wells in high risk of gas migration is carried out by two methods: running production casing up to the surface or a liner to isolate the high pressure zone.

+ The reinforcement of wells by production casing (technical) up to the surface with high cement slurry column will be affected by the rule of pressure reduction in the dangerous phase transition phase period. However, this rule has been effectively controlled by cementing application with a different setting time of cement slurry, and a combination to improve isolation properties of the cement stone in Vietsovpetro.

+ In principle, reinforcement of a well by a liner prevents a dangerous period of phase transition. However, running casing and cementing liner in Vietsovpetro are still complicated and further research is needed to find the root cause and to improve the efficiency.

- Measures to prevent long-term gas migration after cement solidification have not been applied during the drilling period.

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