

Planning UBD in Horizontal Well to Minimize Formation Damage

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Abstract

Underbalanced drilling (UBD) is defined as a condition which generated when effective downhole circulation pressure of the drilling fluid system in touch with reservoir rock is less than presenting formation pressure. Underbalanced drilling (UBD) has been utilized as a mean to eliminate or significantly reduce the problem associated drilling like formation damage which often this problem greatly reduce oil and gas productivity in open hole horizontal well section. The advantage of reduced formation damage results from the fact that the wellbore pressure is intentionally maintained lower than formation pressure during drilling operation. In order to achieve this condition several drilling techniques are used such as aerated drilling, foam drilling which based on low drilling density. In appropriate design or inability to maintain well in underbalanced condition during operation will be potential source of sever invasion damage which linked to several mechanism for damage like spontaneous imbibition, glazing, and macroporosity. Therefore, it is significant to select reservoir candidate carefully, to achieve high profitability.

Furthermore, during UBD formation fluid invade into to wellbore therefore the size and design of surface equipment like separator and reserve tanks are required to handle the produced well fluid. Therefore, the ability to accurately estimate the influx volume and rate of produced fluid is critically significant to size and design surface equipment. In this project a mathematical model has been designed based on rigorous reservoir borehole-cross flow which used to determine the influx volume during UBD and investigate how aerated and foam drilling fluid acts during UBD.

Keywords: UBD; Formation damage; Volume of fluid influx

Nomenclature

J_{sp} = Specific productivity index, stb/d-psi-ft

X = distance from toe of drain hole, ft

X_c = critical distance from toe of drain hole, ft

D_h = borehole diameter, ft

D_p = drill pipe, in

K_v = Vertical permeability, mD

K_h = Horizontal permeability, mD

I_{ani} = permeability anisotropy, dimensionless.

ΔP_f = frictional pressure loss, psi

L_{dr} = length of drained hole section, ft

ΔL = length of increment of Horizontal borehole, ft

L = total length of drilled Horizontal section, ft

d_h = borehole diameter, in

d_p = drill pipe diameter, in

ρ_m = density of mixture, lbm/ ft³

μ_f = formation volume factor of reservoir fluid, rb/stb

h = formation thickness, ft

y_b = distance of boundary from the borehole, ft

S = Skin factor, dimensionless

P_r = reservoir pressure, psi

p_{w(x)} = pressure in wellbore at x from the toe, psi

P_{WH} = pressure at heel of Horizontal section, psi

P_{WT} = pressure at toe of Horizontal section, psi

ρ_{WO} = injected water density, kg/m³

ε = equivalent roughness, in

ε_{out} = borehole roughness, in

ε_{in} = commercial steel casing roughness, in

W_s = weight flow rate of solid, lb/sec

W_l = weight flow rate of liquid lb/sec

Q_g = volumetric gas injection rate at surface, scf/min

Introduction

International Association of Drilling contractors (IADC) has defined underbalanced drilling (UBD) as a technique in which equivalent circulation density (ECD) of drilling fluid is intentionally maintained less than effective formation rock pressure (P_f) in open-hole section at any depth. That results in tendency of fluid to inflow from formation into wellbore.

UBD technique has grown rapidly as alternative technique to conventional drilling (overbalanced) to eliminate or significantly reduce the problem of formation damage in horizontal well.

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However, Bennion and Thomas [1] have stated the possibility of existing formation damage in condition where original saturation of hydrocarbon or water in the reservoir is lower than irreducible saturation of the phase that used in drilling. This lead to spontaneous imbibition is caused by capillary pressure and wettability properties. This generally appears in low permeability gas reservoir which has very low initial water saturation.

According to Marbun et al., [2] UBD could be applied in situation where the possibility of severe loss of circulation exists. For instance, highly fracture sandstone reservoir and high permeability vugular carbonate. In addition, UBD was applied in order to increase the penetration rate through reducing “chip hold down” effect which in turn the solid will be removed more easily.

Minimize the pressure on the bit and improve the bit life is another application of UBD since it is reduced the contact with rock and increase penetration rate [2,3]. One of the significant reasons for growing underbalanced drilling is that it can improve the financial return on drilling process by increasing the productivity once drilled. Influx of formation fluid during UBD provides an opportunity to evaluate the reservoir in real term, so the fluid properties assessment and geological interpretation can be performed while drilling and optimization can be estimated earlier [2].

As mentioned before, the key principle of underbalanced drilling is keeping downhole pressure less than formation pore pressure. This sometimes occur naturally when unweight fluids are used and the reservoir is geostatically over pressured for its depth [1]. However, several low density drilling fluid techniques have been developed to maintain well in underbalanced condition which generally classified into three main groups:

- Single gas phase such as (Dry air, Nitrogen and Natural gas).
 - Single Liquid phase (Flow drilling, Mudcap drilling, lightened drilling).
 - Two phase gas – liquid mixture like (Mist drilling, Foam drilling, Aerated liquid).

However, UBD technique has several economical and technical limitations which prevent its implementation in some circumstances. For instance, problem of wellbore instability during UBD which happens once the bottomhole pressure (BHP) is kept lower than pore pressure. Furthermore, prediction the volume and invasion rate of reservoir fluid (oil, water) through UBD might cause difficulty for drilling engineer because of the complicated connection between drilling and formation fluids and rock nature of penetrated formation, practically in the zone around wellbore which have hydraulic and thermal diffusivities between formation and wellbore [3].

Underbalanced Drilling (UBD) Technique

Underbalance drilling (UBD) can be defined as a drilling technology in which effective hydrostatic head pressure of the circulation drilling fluid system is intentionally designed to be less than the pore pressure of the formations being penetrated. Result in, tendency of formation fluid to flow into borehole (Figure 1).

Motivation of UBD in Horizontal Well

Once underbalanced drilling designed and executed properly, it can eliminate several problems associated with drilling operation which in turn improves financial return and increase oil and gas productivity. For instance, minimizing formation damage which it is

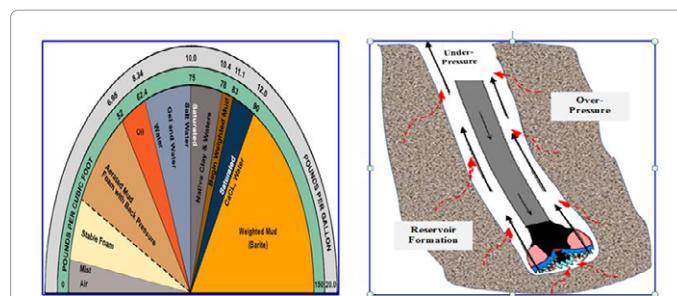


Figure 1: UBD Operationand fluid densities (LEA,2002).

Increased Rate of Penetration (ROP)
Increased bit life
Minimized risk of lost circulation
Reduced probability of differential sticking
Reduced stimulation requirements
Ability to flow/well testing while drilling
Earlier production
Improved formation evaluation

Table 1: General advantage associated with UBD.

generally occur when drilling mud invade the rock formation ($P_w > P_f$). This physical force impede the stream of reservoir fluid into wellbore; consequently, impair permeability near wellbore [4]. This is especially valid for horizontal well since horizontal section perforates greater producing formation distance and this formation is exposed to drilling fluid for a while. However, from the principle of UBD the pressure of wellbore is less than formation pressure ($P_w < P_f$) so it can eliminate solid invasion. However, the difficulty here is how to keep the condition in underbalanced mode during the entire drilling process. Generally, the drilling of long horizontal section generates fiction pressure loss in the annulus which effect on bottomhole of the well and gradually increases the geopressure of the formation which result in reducing rate of penetration.

However, the friction loss in the annulus is reduced in UBD by permitting the energy of reservoir to push fluid out of the borehole [5].

In addition, differential pipe sticking is considered one of the major problems in drilling horizontal due to the fact that drilling string lies at the side of bottom hole when drilling bit is being directed or during pipe connection are performed. During such periods, the movement of pipe is less at the bottom hole which would be perfect situation for differential stick occurrence. However, in UBD prevent problem of sticking pipe due to there will be always flow into borehole and filter cake cannot form [6]. Table 1 shows some other benefits that UBD drilling can be provided over conventional drilling (Overbalanced).

Technical Limitation of UBD in Horizontal Well

Generally, UBD provides several benefits compared to conventional drilling process as illustrated before; however, there are some possible technical limitations associated with this operation when it is not designed and executed properly [6]. Wellbore instability considers as one of the main factor which restrict applying underbalanced drilling in unconsolidated or highly depleted reservoir. This instability comes from mechanically induced due to underbalanced pressure and chemical induced when drilling through formation such as (shale or clay) formation which sensitive to water. These formations might

dehydrate when drilling with gaseous drilling mud or the possibility of absorbing water when mist, foam or aerated are used as drilling which could lead to well destabilization [2]. According to (Bennion and Thomas) [1], the UBD could be a source of sever formation damage horizontal well due to complexity to keep permanent UBD condition through drilling and completion operation.

Drilling Fluid Selection

The key principle for successfully drilling underbalanced horizontal well depend on selecting the right drilling fluid system with its phases which provide low density in order to maintain hydrostatic head pressure of the mud (P_m) below formation pore pressure (P_r). However, improper selection or designing fluid system might cause further formation damage and it also increase the cost of drilling due to downhole fire and corrosion. In order to choose suitable drilling fluid for UBD several factors should be considered such as analyzing petrophysical and geomechanical data, assessment of possible rock damage. The fluid system must design which give BHP less than formation pressure. The ability to transit downhole data should also take into account when selecting fluid system; for instance, gas might reduce bottomhole transmitted signal if used as fluid system. Figure 1 shows different drilling fluid densities.

Selection of UBD Techniques

Gasified (Aerated) drilling operations

This type of drilling fluid is commonly used in horizontal well since it optimized to provide better wellbore instability in open hole section because of its higher pressure gradient compared with other drilling fluids. In gasified drilling system, a mixture of gas and liquid are prepared at surface prior it flow into drill pipe or downhole into liquid phase at the annulus [7]. Any available liquid can be used in the mixture as base for liquid phase, but for gaseous phase (nitrogen, air) gases are the common gases are used. However, gas selection is generally depends on downhole explosion tendencies. One of the major advantages of aerated drilling fluid is ability to eliminate or reduce formation damage since it prevent filter cake and filtrates to enters formation, and prevent differential pipe sticking. Therefore, it can be used in formation where lost circulation and formation damage is considered as major concern. In addition, aerated fluid system highly tolerance to high temperature and its densities ranging from 4-7 ppg.

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Lightened drilling technique

Lightened Drilling fluid can be defined as mixture of two phase gas

and liquid in a particular proportion demanded to achieve a desirable density. Lightened drilling fluid can be classified based on structure and proportions of gas-liquid mixture into (mist and foam). Mist drilling fluid like dry air drilling depends on annular velocity of the hole to circulate out the hole. It also provides minimum water influx due to its higher tolerance [8]. Wellbore instability consider as a main concern when using mist drilling due to the high difference in pressure between formation fluid and mist drilling fluid. The chemical and mechanical encouragement wellbore instability is possible specially when drilling unconsolidated or poorly consolidated formation such as shale. The presence of water phase in mist system can cause borehole collapse especially in shale formation since shale is sensitive to water and leads to shale swelling. A rapid corrosion of downhole equipment is another problem which limiting mist drilling, this is due to presence of high level oxygen concentration in mist system which induce steel corrosion (Figure 2).

Although, adding corrosion inhibitor consider as reasonable solution for protecting downhole equipment from corrosion, McLennan et al., find out that the most successful inhibitor for mist drilling system is organo-phosphate ester.

Since water influx is one of the major issues in most types UBD drilling fluid; therefore, adding agents like (foam or surfactant) to the mixed water or gas phases will create foam drilling system. Generally, there is two basic foam systems are used in UBD operations (Stable foam and Stiff foam). These systems have capacity to absorb large quantities of water and provide a better wellbore cleaning. In addition, one of the distinguishing features of foam is that it has high viscosity and low density properties compared with other types of drilling fluids. The high effective viscosity and velocity provide several benefits in term of circulating out large cutting the drilling cutting to the surface and it able to suspend it for a while after stopping circulation [4]. According to Dahl and Bart Vos [8], foam drilling system (Stable foam) is capable to carry out an influx rate of (500 bb/hr). In addition Harris, [9] stated that foam fluid operation displayed as a good candidate for reducing formation damage in the different reservoirs characteristic that has been applied and in different well types.

Underbalance Reservoir Screening and Selection

Technically, UBD is almost feasible in all situations. However, it is essential prior starting UBD set of reservoir criteria should be taken into consideration which helps to determine whether specific reservoir

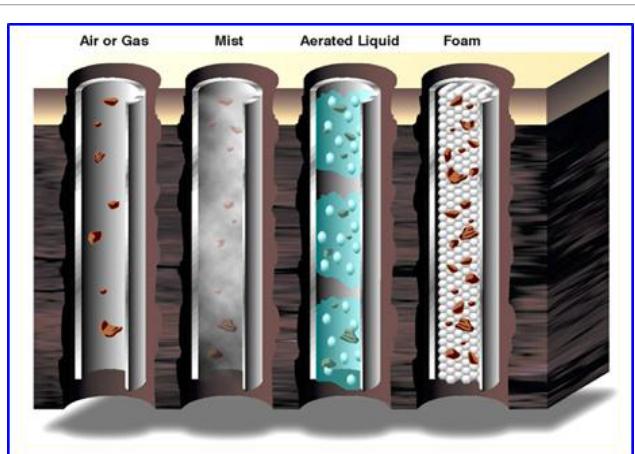


Figure 2: Compressible drilling fluids technologies (Weatherford,2002).

is prime candidate for underbalanced drilling. The Table 2 below based on several previous studies which shows acceptable characteristic for a reservoir to be drilled underbalanced, it also include some unacceptable reservoir indication for UBD [6,9]. Table 3 shows some good candidate for implementing UBD.

Mechanism of Formation Damage in Horizontal Wells (Drilling)

Formation damage considers as a complex phenomenon which caused by several mechanism and generally depending on reservoir characteristic, formation lithology and kind of drilling. Although there are several damage phase exist, a common mechanism which trigger the formation damage in horizontal as follow:

Fines migration

This indicates to mobilization of in-situ fine particles within formation. This movement strongly associated with formation wettability. Generally, this movement tends to be problematic in clastic formation because of higher concentration of mobile materials. In such situations UBD would be utilized to minimize particles migration during drilling and clean -up operations [5]. However, the only possible problem associated with this issue during UBD, if adequate UB pressure present and the high production flow from formation represent the wetting phase. This might lead to early initiation of fine mobilization [10]. These fine particles will build bridge across pore throat which reduce well productivity.

Phase trapping/blocking

This happen due to invasion of drilling fluid oil and water phase into porous medium near to horizontal wellbore region due to several factors like difference between initial water saturation and irreducible water saturation during underbalanced drilling and leak off during overbalanced drilling. This phenomenon could result in constant entrapment of whole or portion of the fluid influx which result in minimize of oil and gas permeability due to adverse relative permeability effect (Figure 3).

Chemical incompatibility of invading fluid (Reactive clay)

Several formations include potentially in situ reactive clay structure like smectite or kaolinite which are susceptible to hydration or deflocculation (clay particles are broken) conditions either by contacting with low salinity water or sudden salinity switch [1]. The

Downhole (Bottomhole) fire
Conventional MWD is ineffective when compressible fluid are used
Poorly managed multiphase flow could create drilling problem.
Possible excessive borehole erosion

Table 2: General disadvantages of UBD.

Reservoir suitable from UBD	Reservoirs generally will not suitable from UBD
Under pressure/depleted formation or mature field.	High pressure zones exhibiting high flow and potential control problem.
Dehydration formations exhibiting subirreducible water saturation or hydrocarbon saturation.	High pore pressure coupled with highly permeable formation
High permeability (>1000 md) consolidated intercrystalline sands and carbonates.	Formation susceptible to spontaneous imbibition.
Formations containing significant concentrations of water-based mud filtrate-sensitive material (clays>1%), anhydrite.	Hole section with various pressure.
Hard rock formation because of well bore stability.	Formation where reservoir knowledge is poor.

Table 3: Reservoir aspect during UBD.

scattered particles tend to plug pore throat. The encouragement of UBD is to reduce the losses of possibility damaging incompatible liquid flowing into formation which tends to create a region near wellbore which is highly permeability deteriorated (Figure 4).

Biological activity (Bacteria)

The bacteria agents (aerobic and anaerobic) which might present in water based fluid which can enter region near wellbore and result in creation of polysaccharide bacteria that consider as waste and reduce near wellbore permeability. UBD can be used to avoid long term losses drilling fluid which might contain viable population of bacteria.

Potential Mechanism of Formation Damage during UBD

Generally, there are several ways in which formation damage could occur during drilling horizontal well such as fine migration, phase trapping, and effect of institute fluid and invading fluid. However, there is also number of possible damage mechanisms associated with underbalanced drilling these include the following.

Lack of potential sealing cake

With appropriate UB drilling operation, the classic bridge filter cake on the surface of the rock is not established due to fluid flowing from formation into borehole and the drilling fluids do not contain any bridging agent. In addition, the complexity to totally maintain drilling in underbalanced condition from the commencement of drilling to the completion stage. This is due to drilling unexpected under pressure

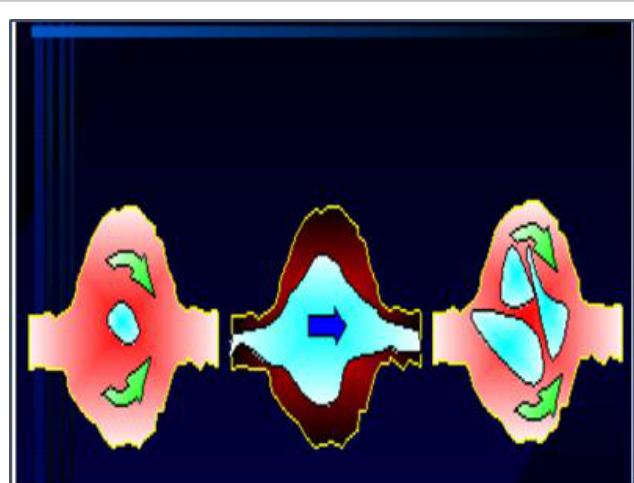


Figure 3: Fine migration and phase trapping mechanisms (Rafique, 2008).

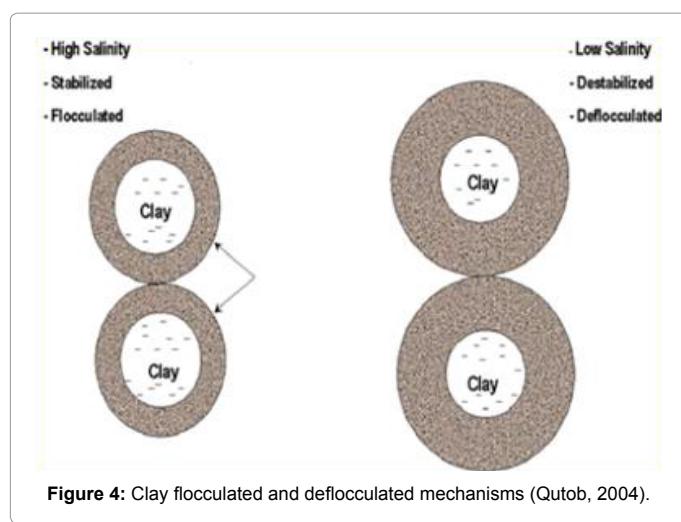


Figure 4: Clay flocculated and deflocculated mechanisms (Qutob, 2004).

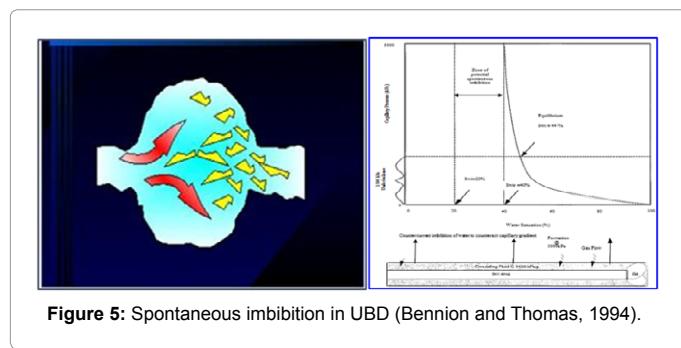


Figure 5: Spontaneous imbibition in UBD (Bennion and Thomas, 1994).

zone, and mechanical or technical trouble which leads to stop of gas pumping [1,11].

Spontaneous imbibition and counter current imbibition

This effect occurs in situations where initial saturation of hydrocarbon or water is less than irreducible saturation of the drilling fluid phase. Then the capillary pressure (P_c) and wettability will cause spontaneous countercurrent imbibition. It is potential for water-based or hydrocarbon-based fluids to imbibe into reservoirs nearby wellbore zones which give rise to minimizing the permeability due to incompatibility influence of rock-fluid or fluid-fluid. This phenomenon will cause the formation matrix to saturate with water by itself. The severity level of countercurrent imbibition is a function of initial water saturation (S_{wi}) and irreducible water saturation (S_{wir}) at capillary pressure (P_c). When P_c becomes close to zero as shown in Figure 5 [1]. In addition, the seriousness of formation damage associated is highly relying on configuration of relative permeability curves for gas phase in low liquid saturation region.

Macroporosity gravity induced invasion

If a large interconnected vug or fracture (macroporosity) formation has been drilled horizontally, the lower side of horizontal well will be invaded by drilling fluid and solid due to gravity force as shown in Figure 6. This phenomenon is a function of underbalanced pressure. When a very large porous formation is drilled at lower underbalance pressure, the fluid superficial velocity will be minimized. As a result, the drilling fluid and solid invade these features, even though the condition is kept underbalanced.

Glazing and mashing damage

Glazing is a polishing of the external surface of wellbore which occurs in pure gas drilling due to lack of heat conductive capacity of drilling fluid to cool and lubricate drilling bit face. The glazing problem often appears severe when high gas injection rate is used for hard formation at low rates of penetration. This problem does not appear in parasite or concentric string. However, when the formation face is polished by inappropriately drilling string centralizing mashing mechanism damage will appear. The depth of potential damage caused by glazing and mashing tends to be shallow. The most formation susceptible to this damage is homogeneous formation.

Economical and Environmental Evaluation of UBD

Generally, UBD technology is demanded by most petroleum producer companies since this technique improves the financial return on drilling wells. This improvement comes from the various benefits that it provides [12]. Even if the cost of drilling wells by UBD is increased, preventing formation damage could increase oil and gas productivity which in turn net present value (NPV) of the well will increase.

However, in some cases this technique is considered as an expensive technique compared with conventional drilling particularly when drilling wells horizontally. For example, using nitrogen gas as drilling fluid to drill extended reach open hole horizontal sections would be costly because of required volume of nitrogen for drilling. However, a portion of this expense may be offset by the benefit which is provided like increasing ROP which results in saving rig time if the well is drilled completely in underbalanced fashion. In addition, an alternative cheap gasification medium such as air can be used but it requires careful monitoring to avoid downhole combustion [1]. Furthermore, the cost of drilling a well by UBD varies depending on the reservoir that is faced and the type of produced reservoir fluid since it requires special surface separation equipment. The number of drilled wells and location of wells have direct impact on mobilization costs.

During execution UBD significant volumes of fluids are produced during UBD and due to combustible properties of these products a great attention must be paid to safety and environmental issues. In order to avoid hazards of explosion, the orientation of hydrocarbon separation and storage should take into consideration by position against wind. However, closed loop systems can be used in underbalanced drilling, so the potential of produced waste drilling fluid would be less and provides additional environmental protection over drilling operations.

Formation Fluid Invasion

Mathematical model

The following mathematical equations have been used to achieve the aim of this project. The formation liquid influx rate equation which has been driven by Guo, Xiaodong has been used [2]. This equation is based on integrating the influx volume over total period for horizontal wells. Figure 7 illustrates horizontal borehole cross flow that is used for deriving the following equation [Appendix]

$$Q_f(x) = \frac{J_{sp}}{2b} \left[\frac{1}{a^2} - \frac{1}{a + bx^2} \right] \quad (1)$$

$Q_f(x)$: flow rate at (x) location (stb/d), L: horizontal borehole section length (ft) and the intermediate parameter (a, b, C and C') equations are :

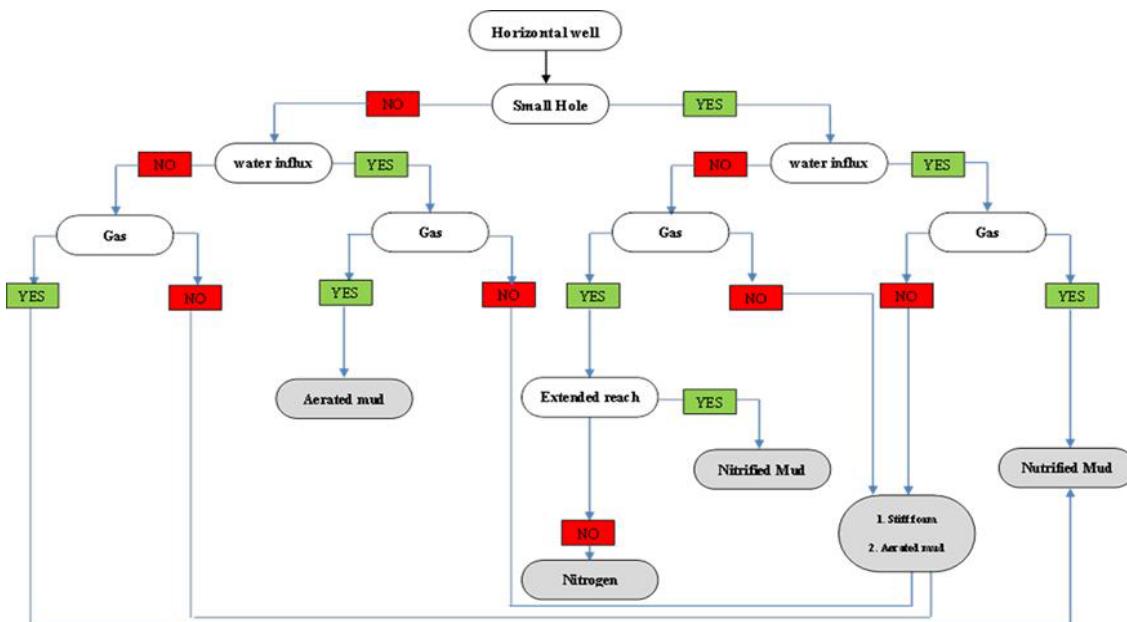


Figure 6: Selection of UBD fluid in horizontal well.

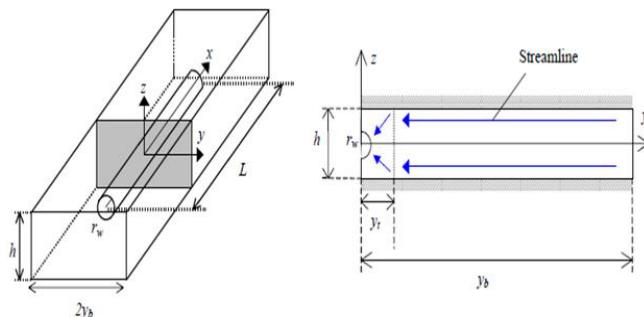


Figure 7: Flow geometry of Horizontal well (Rectangular reservoir).

$$a = \frac{1}{\sqrt[3]{Pr - PwH}} + 0.2752C^{2/3} L \quad (2)$$

$$b = -0.2752C^{\frac{2}{3}} \quad (3)$$

$$C = \frac{2C'}{\sqrt{\frac{6gc(dh - dc)}{\mathcal{F}_f \rho}}} \quad (4)$$

$$C' = \frac{0.012 Jsp}{(dh^2 - dp^2)} \quad (5)$$

The influx rate equation is based on assumption that reservoir flow pattern is turbulent and flow rate of produced fluid increase from toe to heel sections and reach to critical value which known as critical flow rate (Q_{oc}) which is ignored.

In addition, specific productivity index (Jsp) was selected based on reservoir fluid flow conditions which in turn depend on horizontal sections penetrations

$$J_{sp} = \frac{7.08 \times 10^{-3} kh}{\mu_f B_f \left\{ I_{ani} \ln \frac{2h}{D_h(I_{ani}+1)} + \frac{\pi y_b}{h} - I_{ani}(1.224 - S) \right\}}, \quad (6)$$

$$I_{ani} = \frac{\sqrt{kh}}{\sqrt{kv}}. \quad (7)$$

Results and Discussion

It is obvious that during drilling a well horizontally by underbalanced drilling technique the bottom-hole pressure maintained below formation pore pressure. From this concept the fluid will flow from formation into bore hole. Therefore, it is necessary to have an estimation or prediction about the volume and the rate of liquid inflow into to the well. The result of liquid inflow rate and cumulative liquid inflow volume computation for (600 ft) length of horizontal section are shown in the Figure 8 below. The input data is shown in Table 4. It is clear that from the Figure 9, the peak of inflow rate will be (367 ft³/hr) (45 gpm) and cumulative inflow rate (4089 ft³) at the end of horizontal section. Therefore, it is necessary to design a separator which can treat

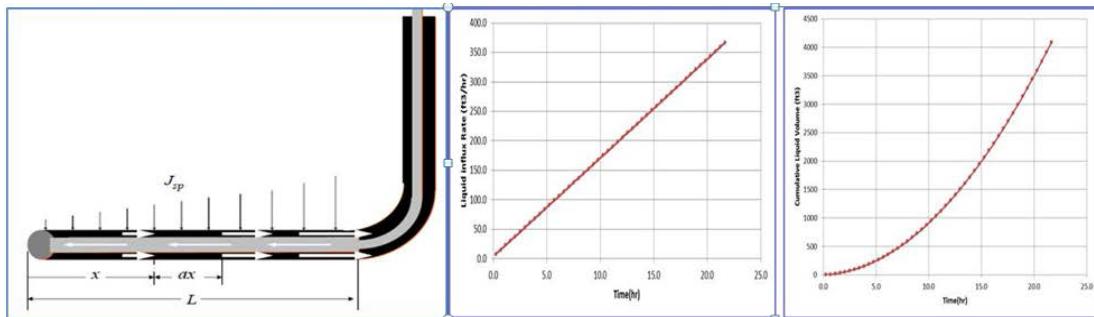


Figure 8: 9-Liquid influx rate and volume at end of horizontal section.

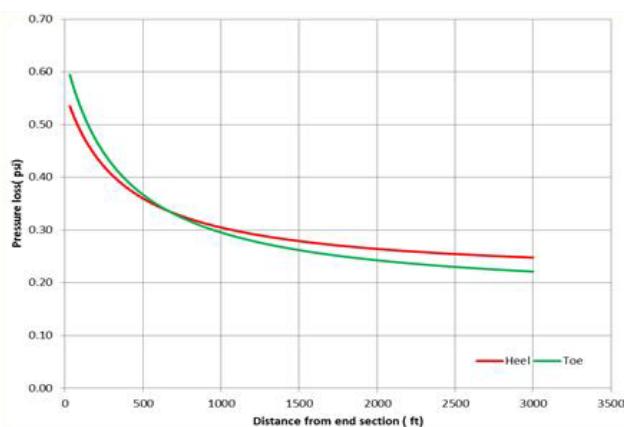


Figure 9: Pressure loss distribution along heel and toe sections.

Pay Zone Thickness (h)	48	ft	Reservoir Pressure	5035	psi
Horizontal Permeability (Kh)	54	md	Bore Hole diameter	7.875	in
Vertical Permeability (Kv)	19	md	Drill pipe diameter	4.5	in
Skin Factor (s)	0		Borehole length	600	ft
Fluid Viscosity (μ)	0.5	cp	Borehole roughness	0.05	in
Fluid formation volume factor (B_f)	1.15	rb/stb	Boundary Distance(y_b)	2000	ft
Fluid density (ρ_f)	51	lb/ft³	Penetration Rate (R_p)	27.69	ft/hr
UB drawdown pressure	535	psi			

Table 4: Reservoir input data.

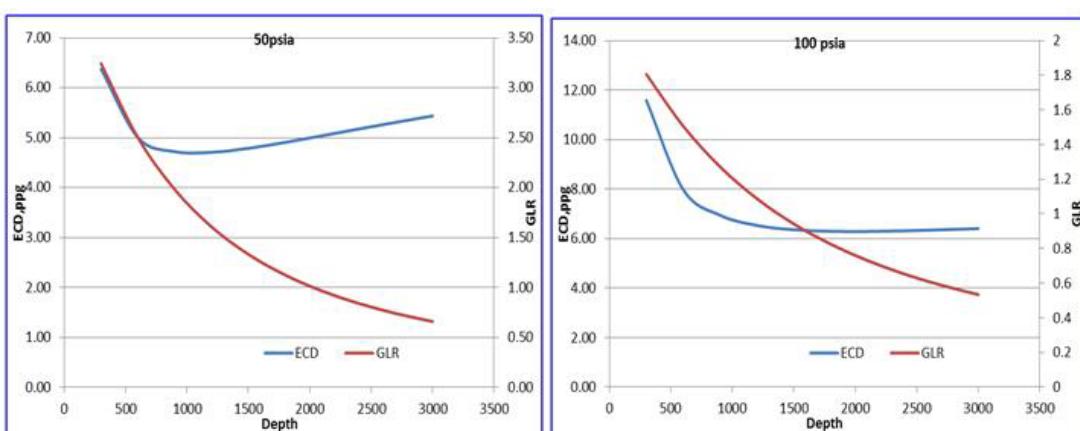


Figure 10: Effect of choke pressure on ECD and GLR.

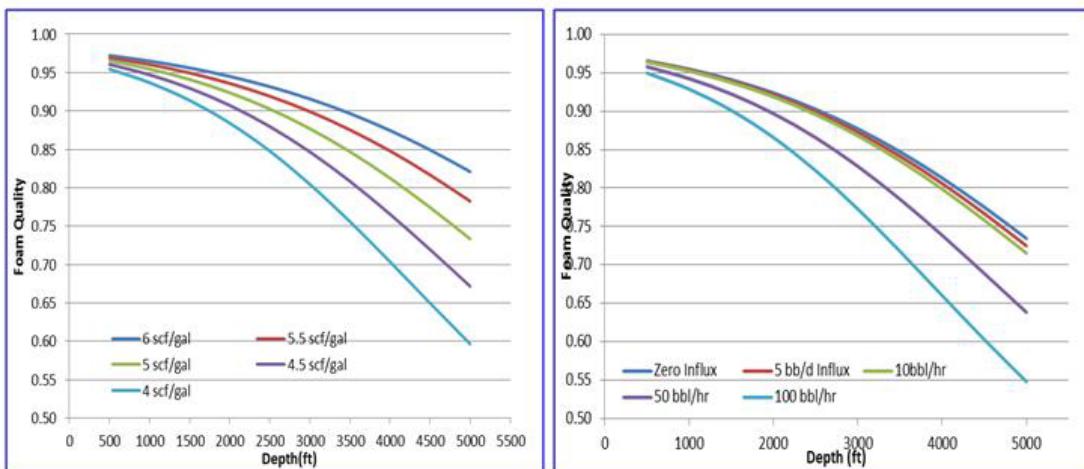


Figure 11: Effect of influx and gas injection on foam quality.

Time (hr)	Horizontal penetration (L)	Liquid Influx rate (ft ³ /hr)	Cumulative influx volume (ft ³)
0.2	7.6	7.6	1.6
0.7	15.2	15.2	8.6
1.1	22.8	22.8	19
1.6	30.4	30.4	32.8
2	38	38	50.2
2.5	45.6	45.6	71
3	53.2	53.2	95.2
3.4	60.8	60.8	123
3.9	68.5	68.5	154.2
4.3	76.1	76.1	188.9
4.8	83.7	83.7	227
5.2	91.3	91.3	268.7
5.7	98.9	98.9	313.8
6.1	106.5	106.5	362.4
6.6	114.2	114.2	414.4
7.1	121.8	121.8	470
7.5	129.4	129.4	529
8	137.1	137.1	591.5
8.4	144.7	144.7	657.5
8.9	152.3	152.3	726.9
9.3	160	160	799.9
9.8	167.6	167.6	876.3
10.2	175.2	175.2	956.2
10.7	182.9	182.9	1039.6
11.2	190.5	190.5	1126.5
11.6	198.2	198.2	1216.5
12.1	205.8	205.8	1310.7
12.5	213.5	213.5	1408.1
13	221.1	221.1	1508.9
13.4	228.8	228.8	1613.2
13.9	236.4	236.4	1721.1
14.4	244.1	244.1	1832.4
14.8	251.8	251.8	1947
15.3	259.4	259.4	2065.5
15.7	267.1	267.1	2187.3
16.2	274.7	274.7	2312.5
16.6	282.4	282.4	2441.3

17.1	290.1	290.1	2573.6
17.5	29.8	29.8	2709.4
18	305.4	305.4	2848.6
18.5	313.1	313.1	2991.4
18.9	320.8	320.8	3137.7
19.4	328.5	328.5	3287.5
19.8	336.2	336.2	3440.8
20.3	343.9	343.9	3597.6
20.7	351.6	351.6	3757.9
21.2	359.3	359.3	3921.7
21.6	367	367	4089.1

Table 5: Results of Mathematical Influx prediction.

this rate of influx and the tanks should be chosen to handle 4089 ft³ of the produced liquid (Figure 10).

Figure 11, shows pressure loss distribution along each section and it is clear that the pressure loss near the toe is higher than heel this is due to turbulence flow at the end section of horizontal well because the drilling fluid pumping path through drilling string into annulus. There is a slightly pressure decrease around heel section. It is necessary to have an estimation value about the amount of injection gas required for drilling horizontal well by UBD (Table 5).

It is also discovered that different choke pressure (50 Pisa) and (100 Pisa) at constant gas and mud injection rate (300 scfm and 150 gpm) could effect on Equivalent circulation density (ECD). It is clear that with increasing surface pressure the equivalent circulation density increase from (5.44 to 6.4 at 3000 ft). This should be taken in consideration when selecting casing depth to prevent formation breakdown. In addition, this project has find out that how formation influx could impact on in situ foam quality. It is obvious from the Figure below that by increasing influx rate the foam quality reduced. Generally, typical foam quality range from (0.55-0.97), if it goes above this rage the foam structure become unstable and foam turn to mist. The foam quality also is influenced by the rate of gas liquid ratio injection. By reducing this ratio the foam quality is reduced as shown in the Figure 11 and (Table 6).

Conclusions

Several potential damages could appear during UBD such as spontaneous imbibition (generally occur when initial reservoir

$a = \frac{0.0014db^2 + SsRp + 0.25WmQm + 1.44(SwQw + SoQo) + 0.019 Sg Qgo}{TQgo} \cos(\theta)$
$b = \frac{0.033Qm + 0.0233(Qw + Qo)}{TQgo}$
$c = \frac{9.77TQgo}{A}$
$d = \frac{0.33Qm + 0.22(Qw + Qo)}{A}$
$e = \frac{f}{2gDH \cos(\theta)}$
$M = \frac{cde}{1 + d^2e}$
$N = \frac{C^2e}{(1 + d^2e)^2}$

Table 6: Aerated mathematical equations.

saturation is less than irreducible saturation of drilling fluid phase), glazing and mashing, macroporosity due to improperly designing and executing UBD program. It is also necessary to continuously monitor and adjusted the UBD draw-down as required in order to handle the quantities of produced fluid while drilling and ensure small liquid gains during process.

It is concluded that, in some period the pressure at end section of horizontal well will reach to formation pressure due to losses of the fictional pressure across borehole. Therefore, it can be seen overbalance condition in the toe section while heel section remains underbalanced. It became obvious during pipe connection process some inflow occurs since the drilling fluid is not pumped down during this process. The volume of the influx during pipe connection could be even higher as a result of lower BHP at this time.

Recommendations

This study is carried out based on mathematical model in order to achieve its aim due to unavailability of software which can deal with UBD in horizontal well. In addition due to time limitation, the recommendation and suggestion for further study and research in such field are:

Perform experimental study to find out how effective underbalanced drilling for removing formation damage in dual lateral horizontal well.

Find out the effect of pressure distribution on liquid formation volume factor across borehole.

Take into account rate of penetration rate as function of wellbore pressure.

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