Rudarsko-geološko-naftni zbornik	Vol. 6	str. 121–126	Zagreb, 1994.

UDC 622.279

Stručni članak

The project »Optimization of dynamic seals in petroleum engineering« financed by the Ministry of Science and Technology of the Republic of Croatia

PARTICULARS IN KILLING GAS PRODUCTION WELLS

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Key-words: Killing, Fluids

To kill a production well means to perform some technical and technological processes for establishing the static hydraulic balance in the well with no additional surface pressures. The standard procedure of the well killing process as adopted in Croatia, is described. Further, the procedures of how to locate the spot where there is a leakage on production equipment and how to determine the level of fluid in tubing or annulus is explained. Finally, the aim of this paper is also to point out the importance in selection of killing fluids considering a possibility of formation damage.

Ključne riječi: Gušenje, Fluidi

Pod pojmom gušenja proizvodnih bušotina, podrazumijevaju se tehnički i tehnološki postupci kojima je cilj uspostavljanje statičke hidrauličke ravnoteže u bušotini, odnosno otklanjanje pretlaka na ušću bušotine. Opisano je provođenje standardnog postupka gušenja usvojenog u Hrvatskoj. Prikazan je način određivanja mjesta propuštanja proizvodne opreme i utvrđivanja nivoa fluida u tubingu i prstenastom prostoru. Posebno je ukazano na važnost izbora fluida za ugušivanje s obzirom na moguće oštećivanje formacije.

Methods for Production Well Killing

The most frequent reason for killing production wells is a necessity to eliminate formation pressures so as to enable certain procedures or removal of some parts of production equipment. Sometimes, however, the killing is necessary due to some undesirable occurrences in the well (leakage or damage of the production equipment). This is known as emergency killing. In the process of well killing it must be taken care not to: cause formation damage, additionally damage subsurface or surface production equipment, exceed the allowed stresses of production or other equipment. The methods for well killing can be devided into four groups considering their applications: (1) well killing by injecting the formation fluids into production layer; (2) circulating methods; (3) gravitation methods; (4) combined methods (Rehm, 1976) The structure of most gas producing wells in Croatia anticipate the method of injecting the formation fluids from the well into the production layer. All other methods have turned to be less efficient and are mostly applied to drilling phase in well constructon. Killing procedure consists of the following phases:

— the formation and service fluids are being injected by killing fluid from the wellbore (tubing) into the formation;

— the fluid injection is terminated when the killing fluid reaches the layer;

— the static balance have to be checked at particular parts of the wellbore (tubing/annulus);

— the packer fluid must be replaced if it does not meet the required density or characteristics.

The injection pressure at the perforation level depends on the formation production properties, physical properties of the fluid to be injected into the formation and on the killing fluid pumping rate. The injection pressure at the surface also depends on the flow regime and properties of the fluid used for well killing. It is also necessary to be acquainted with the formation pressure sensitive range for particular volume of acceptance, as well as with the pressure values of formation fracture.

When killing a well, the hydrostatic pressure must be established to balance the formation pressure. This condition of the hydrostatic balance is valid for the static conditions. When there is a circulation in the wellbore, the pressure will grow equivalently to the pressure drop created by fluid circulation. When the circulation stops, the total pressure value will decline in the equivalent amount. The pressure drop when pulling out the production equipment is up to 1 MPa in the production wells of Drava Region. As a complementary safety value, it is necessary to over pressure the formation, which usually amounts from 1 to 2 MPa. The necessary killing fluid density is then derived as:

$$p_k = p_f + p_{fp} + p_r \tag{1}$$

$$\rho_k = \frac{p_f + p_{fp} + p_r}{g \cdot H_f} \tag{2}$$

The over pressure can cause the loss of well killing fluid which may penetrates into formation. To prevent this, it is necessary to inject a so called gel plug before circulating the killing fluid. The gel plug composition is based on well killing fluid with addition of materials for increasing viscosity and sometimes plugging material is added. The differential pressures that can be endured by such gels are from 3 to 4 MPa of difference between the total hydraulic pressure of killing fluid and formation pressure. The volume of the injected gel amounts from 1 to 10 m³ and depends on the length of the uncovered interval.

Killing Fluids

All porous formations are likely to be damaged to certain rate. The damage can be caused due to filtrate influence on clay component in formation, or particles invasion into formation, or interaction occurring between drilling and formation fluids.

The zone of production can be protected from damage if the killing fluid is properly chosen (non polluting fluid). In choosing the killing fluid it is necessary to take into account: fluid properties, well conditions, and formation parameters.

To achieve that fluid meets its purpose at the best possible manner, the following should be take into consideration:

— fluid density must comply with formation pressure,

— fluid must not have negative impact on uncovered production formation, and

— fluid must be compatible with formation fluid and formation itself.

Table 1 lists potential killing fluids and their properties.

Table 1. Killing fluids

Killing fluids *Fluidi za ugušivanje*	Density *Gustoća* (kg/m³)	Temperature *Temperatura* (°C)
Brines *Vodene otopine soli*		
NaBr	1000 to/*do* 1500	
KCl	to/*do* 1164	
NaCl	to/*do* 1200	120 to/*do* 150
$CaCl_2$	to/*do* 1392	
$NaCl/CaCl_2$	to/*do* 1300	120 to/*do* 150
$CaBr_2$	to/*do* 1704	
$CaCl_2/ZnBr_2$	1392 to/*do* 1820	>180
$CaCl_2/CaJ_2$	to/*do* 2060	>180
$CaCl_2/ZnCl_2$	to/*do* 1920	>180
$ZnBr_2/CaBr_2/CaCl_2$	to/*do* 2304	
Oils/*Ulja*		
Diesel oil *Dizel ulje* (D-1)	840	to/*do* 230
Crude oil *Sirova nafta*	840 to/*do* 950	> 180
Polymer systems *Polimerni sustavi*		
Saturated brine + polymer *Zasićena otopina soli + polimer* + $CaCO_3$ ili $FeCO_3$	to/*do* 1620	150
Brine+polymer +oil soluble resin *Otopina soli+polimer +uljnotopiva smola*	Brine density *Gustoća otopine soli*	150
Saturated brine + polymer + sized salt *Zasićena otopina soli + polimer + zrna soli*	to/*do* 1680	150

At killing well an overbalanced column must be maintained ($p_k > p_f$), and prevention of impairment requires the use of non-damaging fluid. Damage to water-sensitive formations may be prevented by using brine fluids (sodium, potassium and calcium chloride brines). Calcium and potassium chlorides have about the same inhibiting power, but calcium chloride suffers from the disadvantage that it may cause impairment by precipitating carbonates or sulphates, which are often present in formation waters. Therefore, unless high densities are required, potassium chloride is preferred (Martinko, 1991).

All field brines contain solids, although the amount may be very small. In wells with low permeability reservoirs, these solids filter out on the bore hole wall, causing a little, if any, impairment. In wells with medium to high permeability reservoirs, the particles are carried into the reservoir with the brine, and may cause severe impairment, because the volume of brine entering the formation is very high (owing to the lack of filtration control), although their concentration in the brine is low. The particles contaminating the brine may come from the source water or from the sacked salt, or they may be picked up in tank trucks or rig pits. A 2 μm cotton filter may reduce the content of solids. The killing fluid should have filter-loss control whenever necessary to prevent substantial invasion into formation. Damage caused by killing fluid can be avoided if all solid components of the fluid (gel plug), including filtration control agents and viscosifiers, bridging solids, and particular weighting materials are degradable. Various types of soluble or degradable materials are available commercially, and choice between them depends on reservoir conditions and type of operation.

Long chain polymers are used in killing fluids to obtain rheological properties, and, in some cases, filtration control. The bridging agents added to the suspension prevent deep invasion of polymer into the formation. The bridging particle sizes must be from 1/3 to 1/2 of the size of pore openings. The most often used polymers are hydroxyethylcellulose (HEC), derivates of guar gum and starch derivatives. HEC is almost completely soluble in acid. Derivates of guar gum, such as hydroxyethyl and hydroxypropyl are degradable, leaving only from 1 to 2% residue. Starch derivatives, such as hydroxyalkylated and esterified starches are almost completely acid soluble.

Sized particles of oil-soluble resins or waxes may be used as bridging agents for oil reservoirs. Any particles left in or on the formation are dissolved when the well is brought into production.

Ground calcium carbonate is commonly used as a bridging agent, and may be used in any type of reservoir. It is completely soluble in acid, and on completion of the job, it can be removed with acid if necessary. $CaCO_3$ is available in a wide range of particle sizes, from several milimetres down to hundredths of micrometer, and may be used at any temperature encountered in an oil well.

Density control can best be achieved with soluble salts. Maximum densities are as follows: sodium chloride, 1200 kg/m^3; calcium chloride, 1390 kg/m^3; calcium bromide, 1820 kg/m^3; and combined with $CaCl_2$, 1810 kg/m^3; or with $CaCl_2/ZnBr_2$, 2300 kg/m^3. When the high cost of $CaBr_2$ cannot be justified, densities up to about 1680 kg/m^3 may be obtained with ground $CaCO_3$. If densities greater than 1680 kg/m^3 are required, they can be obtained with ferrous carbonate (siderite) — $FeCO_3$. A fluid which uses sized grains of sodium chloride as bridging and weigthing agents may be also used in well killing procedure. The grains are suspended in saturated brine by a polymer and a dispersant (both unspecified). Densities up to 1680 kg/m^3 are attainable. When the well is brought into production, the salt grains are removed by formation water, or the well can be cleaned by flushing wit under saturated brines (Mondshine, 1977). In our practice, this type of fluid has not been used yet.

The Well Killing Procedure

The killing procedure depends on wellbore conditions and the set in production equipment. According to the direction of killing fluid circulation, the killing is considered direct or indirect. In case the fluid is injected back into the formation, it is necessary to establish the communication between the inside of the tubing and annulus after the fluid and gel have been injected, which enables a complete replacement of workover fluid when necessary. This communicaton is possible through the installed circulation tools, or by inactivating the packer, or disconnecting at the safety joint, and similar, relative to the installed production equipment.

Relative to the pressures at the wellhead before killing and the allowed working pressure of the equipment used in the killing procedure the fluid volume is established upon which the circculation pressure depends. The killing volume must be constant for the time unit in the course of the procedure. Pressure fluctation during the killing procedure can cause the inflow of formation fluid into the killing fluid which may end with udesirable problems. Everybody who deals with gas well killing must all the time bear in mind characteristic gas behaviour as presented in Fig. 1.

The amount of gas that penetrates into the killing fluid in the mishandled killing procedure, changes the volume during gravity lifting in the closed wellbore. Coming to the surface the pressure of fluid column compressing the gas drops and gas volume grows retaining the formation pressure. When gas reaches the surface, the gas-/formation pressure is added to the hydrostatic

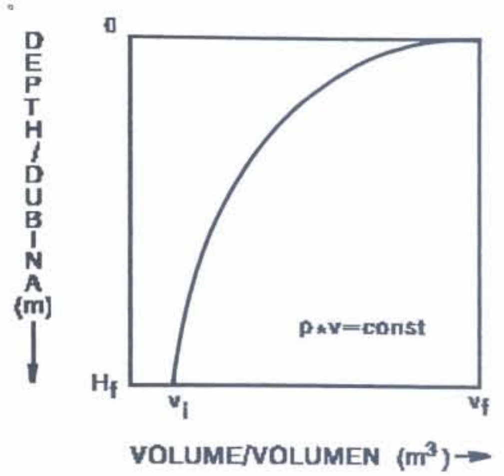


Fig. 1. Gas volume relative to the fluid column pressure
Sl. 1. Promjena volumena plina s obzirom na tlak na bušotini

pressure of killing fluid. So added these two pressures may fracture formation, cause loss of killing fluid and severe accidents with possible loss of wellbore and equipment as well. Fig. 2 shows the diagram of pressure on the wellbore bottom in the course of killing. Fig. 3 shows the pressure changes at the killing line at the wellhead regardless to circulation direction.

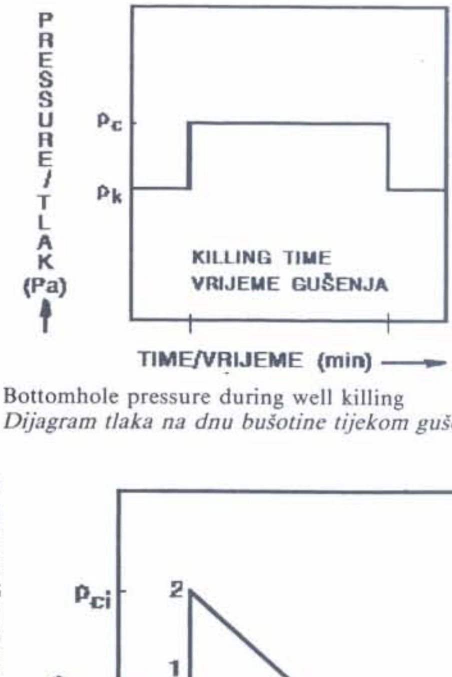


Fig. 2. Bottomhole pressure during well killing
Sl. 2. Dijagram tlaka na dnu bušotine tijekom gušenja

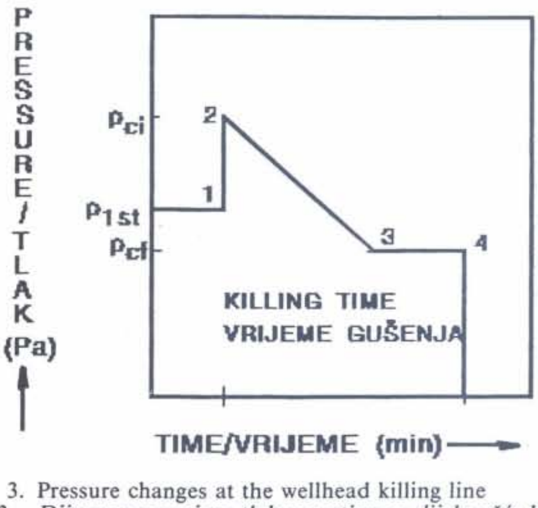


Fig. 3. Pressure changes at the wellhead killing line
Sl. 3. Dijagram promjene tlaka na utisnom dijelu ušća bušotine tijekom gušenja

Wellhead static pressure which in accordance with the circulation direction may occur in tubing or annulus (read off from the pressure gauge), describes equation (3):

$$p_{ci} = p_{1st} + p_c + p_r \quad (3)$$

The diagram area from point 2 to point 3 represents the filling of tubing or annulus with killing fluid relative to direction of fluid circulation. The pressure at the killing line must be adjusted all the time by accurately observing the injected volume in the course of time or number of pump motions.

The filling of tubing or annulus, overcomes the pressure in the wellhead that results from insufficient fluid pressure column as it previously existed in the wellbore. When killing fluid reaches the hole bottom, it is necessary to further maintain the final circulation pressure constant (point 3 to 4), during which time the outlet side is being filled up with the killing fluid. Final circulation pressure describes equation (4):

$$p_{cf} = p_{ci} - p_{1st} \cdot \frac{\rho_k}{\rho_p} \quad (4)$$

Fig. 4 presents a diagram of the pressure change at the hole outlet at the wellhead. Diagram area from point 2 to point 3 represents time of filling the upward side with maintaining the pressure at the outlet constant. Area from point 3 to point 4 indicates the lifting of brine at the outlet, what reduces pressure at the surface to the point of complete fluid replacemet.

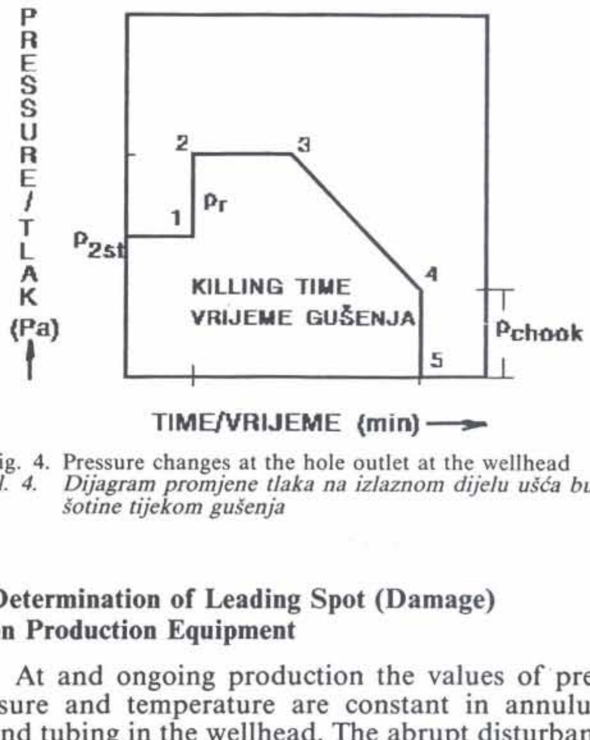


Fig. 4. Pressure changes at the hole outlet at the wellhead
Sl. 4. Dijagram promjene tlaka na izlaznom dijelu ušća bušotine tijekom gušenja

Determination of Leading Spot (Damage) on Production Equipment

At and ongoing production the values of pressure and temperature are constant in annulus and tubing in the wellhead. The abrupt disturbance of these values shows that there has been a damage on production equiment, what calls for an emergency killing. When possible, it is useful to locate the place of leakage on production equipment, or least the fluid levels in the hole after the static hydraulic balance has been established.

The graphical method of determining the place where there is a leakage on the production equipment is illustrated in the Fig. 5. (Pavić and Omrčen, 1992).

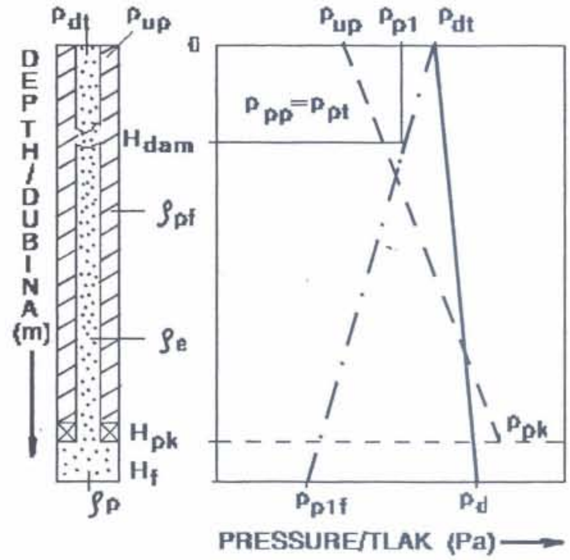


Fig. 5. Graphical method for leaking place determination
Sl. 5. Grafička metoda određivanja mjesta propuštanja proizvodne opreme

The indicated line of pressure along the tubing can be determined upon the measured value of dynamic pressure and value of dynamic pressure at the tubing on the surface (p_{dt}). The grade of killing fluid hydrostatic pressure and dynamic pressure value at the production formation level is obtained by measurements at the hole bottom.

The line of pressure in annulus is calculated upon the measured value at the annulus on the surface (p_{ut}) and the gradient of hydrostatic pressure of packer fluid.

The line of leakage on the production equipment is obtained upon dynamic pressure value at tubing outlet and the value of equivalent formation fluid density (ρ_e). The line is the sum of actual formation fluid density and the one derived from pressure gradient of friction produced by fluid circulation through production equipment. The equivalent density can be determinated from:

$$\rho_e = \rho_p + \rho_f \,(kg/m^3) \quad (5)$$

$$\rho_f = \frac{p_{fcirc}}{g \cdot H_f} \,(kg/m^3) \quad (6)$$

$$\rho_e = \frac{\rho_p + p_{fcirc}}{g \cdot H_f} \,(kg/m^3) \quad (7)$$

At the spot of leakage on production equipment the pressures inside annulus (p_{pp}) and tubing (p_{pt}) will come to balance. To determine the spot of leakage on production equipment, the pressure observed at annulus outlet at the moment of leakage is relevant figure. The spot of leakage on production equipment is determined by equation:

$$H_{dam} = \frac{(p_d - p_{pl}) - g \cdot H_f \cdot \rho_e}{g \cdot (\rho_{pf} - \rho_e)} \quad (m) \qquad (8)$$

The leakage line on production equipment is designed upon complementary values of annulus pressure at the moment of leakage on the equipment (p_{pi}), for $H_{dam} = 0$ and $H_{dam} = H_f$:

for $H_{dam} = 0$ $\qquad p_{pl} = p_{dt}$ (Pa)
for $H_{dam} = H_f$ $\qquad p_{plf} = p_d - g \cdot H_f \cdot \rho_{pf}$ (Pa)

It will cause the change in pressure which could be observed in annulus and at the wellhead. Since leakage occurs in a closed hole, the pressure changes will last until the establishment of static hydraulic balance of the fluid in the hole, which means until the gravity displacement ends. In Fig. 6 there is a schematic illustration of hydraulic balance restoration in a closed hole after occurrence of leakage on production equipment accompanied with relevant designations.

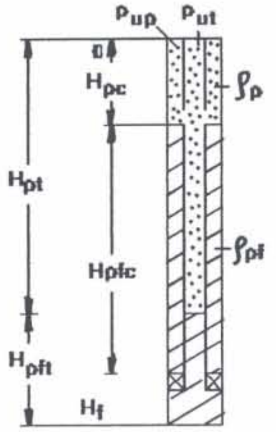


Fig. 6. Balance restoration in a closed hole
Sl. 6. Shematski prikaz uspostavljenog ravnotežnog stanja nakon propuštanja proizvodne opreme u zatvorenoj bušotini

The pattern for determining the fluid distribution in tubing is as follows:

$$H_{pft} = \frac{p_f - p_{ut} - g \cdot H_f \cdot \rho_p}{g \cdot (\rho_{pf} - \rho_p)} \ (m) \qquad (9)$$

$$H_{pft} + H_{pt} = H_f \ (m) \qquad (10)$$

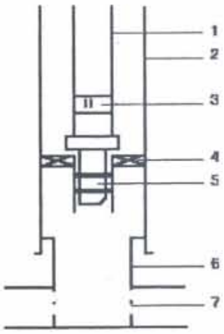
The pattern for determining distribution of fluid in casing is as follows:

$$H_{pc} = \frac{p_{ut} - p_{up} + g \cdot H_{dam} \cdot (\rho_p - \rho_{pf})}{g \cdot (\rho_p - \rho_{pf})} \quad (m) \qquad (11)$$

$$H_{pfc} + H_{pc} = H_f \quad (m) \qquad (12)$$

Description of Killing Procedure of Gas Production Well Stari Gradac-5

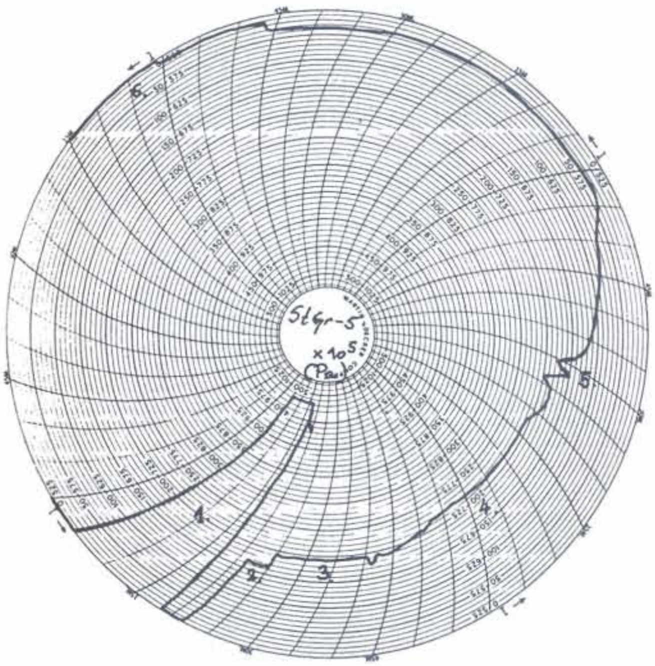
The Stari Gradac-5 is a gas production well of Podravina sedimentary basin. In Fig. 7 there is its schematic presentation (Mršić, 1992).



1. TUBING / PROIZVODNI NIZ CIJEVI
2. CASING / ZAŠTITNE CIJEVI
3. SLIDING DOORS / KLIZNA VRATA
4. PACKER / PAKER
5. SEALING ASSEMBLY / BRTVENICA
6. LINER / LAJNER
7. PERFORATIONS / PERFORACIJE

Fig. 7. Schematic of Stari Gradac — 5 well completion
Sl. 7. Shematski prikaz bušotine Stari Gradac — 5 s ugrađenom proizvodnom opremom

Reason for killing the CRO-1 producton well was in the fact that formation pressure dropped, and that in order to enhance the recovery it was necessary to replace the tubing, wellhead and packer fluid. The killing procedure method applied in that case was injecting the formation fluid from the tubing back into the formation. The density of brine used in the killing process amounted to 1170 kg/m^3.



1. KILLING LINE PRESSURE TESTING/*ISPITIVANJE VODA ZA GUŠENJE*
2. MASTER VALVE OPENING/*OTVARANJE GLAVNOG VENTILA*
3. GEL PLUG INJECTION/*UTISKIVANJE GEL ČEPA*
4. KILLING FLUID INJECTION/*UTISKIVANJE FLUIDA ZA GUŠENJE*
5. GEL PLUG INJECTION THROUGH PERFORATIONS/*PROTISKIVANJE GEL ČEPA KROZ PERFORACIJE*
6. PRESSURE CHECK ON TUBING HEAD/*PROVJERA TLAKA NA GLAVI TUBINGA*

Fig. 8. Killing process diagram Stari Gradac — 5
Sl. 8. Dijagram bušotine Stari Gradac — 5

In Fig. 8 there is a diagram obtained upon registered values in the killing process. Observing the diagram it is possible to monitor the sequence and efficiency of killing process. For the subject well, before the separating gel plug was injected, the pressure of 15.51 MPa had been pumped up, after which the main valve was opened. At the moment of opening the pressure at the wellhead amounted to 17.24 MPa. The killing started by injecting 1.3 m^3 of gel which was further circulated by brine. In the course of injection the pressure on the pressure gauge grows due to the resistance occurring during killing fluid circulation. At the point where formation fracturing pressure was reached, the formation fluid was injected back into formation, Next pressure grow was registered at the moment when gel plug passed through perforations. The continuation of killing process include implicity establishment of communication between tubing and annulus as well as continuation of packer fluid replacement by killing fluid. After the pure killing fluid emerge at the wellhead outlet, the circulation should be stopped. If the well rests, killing process may be considered well done.

Conclusion

The procedure of well killing is considered to be a very complex. Irregularities in its performance may cause many disturbances which are lately difficult to restore. First of all, formation can be damaged what results in reduced permeability of a reservoir and consequently reduced production. The damage of production equipment is also possible. In order to prevent those damages, in cases the damages are identified, it is necessary to thoroughly plan the procedure of killing process, once it has been decided the procedure should be performed.

One of the basic prerequisites in succeding in the killing procedure is the adequate selection of killing fluid. From this point, the most important is that chosen fluid is possible to create necessary pressure and that it is compatible with formation fluids and reservoir rocks.

In the course of process, all changes of values relevant for the process should be observed so that they do not overcome allowed amounts. First of all, it is meant for amounts of pressures that exist at certain portions of the wellbore or in certain parts of equipment.

Received: 12.I. 1994.
Accepted: 9.VI. 1994.

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Symbols/ *Popis simbola*

g — gravity / *ubrzanje sile teže*, m/s²

H_{dam} — depth of leakage on production equipment/ *dubina propuštanja proizvodne opreme*, m

H_{pft} — the height of packer fluid column in tubing/ *visina paker fluida u tubingu*, m

H_f — formation depth/ *dubina formacije*, m

H_{pc} — the height of formation fluid column in annulus/ *visina stupca proizvodnog fluida u prstenastom prostoru*, m

H_{pfc} — the height of packer fluid column in annulus/ *visina stupca paker fluida u prstenastom prostoru*, m

H_{pk} — packer depth/ *dubina pakera*, m

H_{pt} — the height of formation fluid column in tubing/ *visina stupca proizvodnog fluida u tubingu*, m

p_c — circulation pressure at defined capacity/ *tlak cirkuliranja kod određenog kapaciteta sisaljke*, Pa

p_{cf} — final circulation pressure/ *konačni tlak utiskivanja*, Pa

p_{ci} — initial circulation pressure/ *početni tlak utiskivanja*, Pa

p_{chok} — resistance pressure to flow through choke/ *tlak otpora protjecanju kroz sapnicu*, Pa

p_d — dynamic pressure at formation level/ *dinamički tlak na razini sloja*, Pa

p_{dt} — dynamic pressure at tubing outlet/ *dinamički tlak na glavi tubinga*, Pa

p_f — formation pressure/ *tlak formacije*, Pa

p_{fp} — pressure drop created by friction when pulling out the equipment/ *pad tlaka zbog trenja kod izvlačenja alatki*, Pa

p_{fcirc} — pressure of fluid friction in production equipment during production/ *tlak ostvaren trenjem pri protoku fluida kroz proizvodnu opremu*, Pa

p_k — hydrostatic pressure of killing fluid column/ *hidrostatički tlak stupca fluida za gušenje*, Pa

p_{pp} — pressure in annulus at the spot of leakage/ *tlak u prstenastom prostoru na mjestu propuštanja*, Pa

p_{pk} — annulus pressure at packer level/ *tlak u prstenastom prostoru na razini pakera*, Pa ($p_{pk} = p_{up} + H_{pk} \cdot \rho_{pf} \cdot g$)

p_{pt} — pressure in tubing at the spot of leakage/ *tlak u tubingu na mjestu propuštanja*, Pa

p_{pl} — pressure at annulus outlet at the moment of leakage/ *tlak na izlazu iz tubinga u trenutku propuštanja*, Pa

p_{plf} — pressure at the tubing bottom at the moment of leakage for $H_{dam} = H_f$/ *tlak na dnu tubinga u trenutku propuštanja za* $H_{dam} = H_f$, Pa

p_s — safety value — over pressure/ *sigurnosna vrijednost pretlaka*, Pa

p_{up} — pressure at annulus outlet/ *tlak na ušću u prstenastom prostoru*, Pa

p_{1st} — wellhead static pressure which in accordance with the circulation direction may occur in tubing or annulus, read off from the pressure gauge/ *statički tlak na ušću, koji ovisno o smjeru utiskivanja može biti u tubingu ili prstenastom prostoru, očitan na manometru*, Pa

p_{2st} — static pressure at the fluid outflow from the hole/ *statički tlak fluida na izlaznoj strani*, Pa

v_i — initial gas volume/ *početni volumen plina*, m³

v_f — final gas volume/ *konačni volumen plina*, m³

ρ_e — equivalent formation fluid density/ *ekvivalentna obujamska masa slojnog fluida*, kg/m³

ρ_f — density derived from pressure gradient produced by fluid friction when producing/ *obujamska masa određena iz gradijenta tlaka ostvarenog trenjem pri protoku fluida kroz proizvodnu opremu*, kg/m³

ρ_k — killing fluid density/ *obujamska masa fluida za gušenje*, kg/m³

ρ_p — wellbore fluid density/ *obujamska masa slojnog fluida*, kg/m³

ρ_{pf} — packer fluid density/ *obujamska masa paker fluida*, kg/m³