

Unconventional technology for sealing and P&A of wells for prevention of global environmental disasters

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Abstract. Many, if not all of the oil and gas fields under development, have leaking wells. There are a lot of so-called abandoned, ownerless wells. Subsoil users, by one way or another, make efforts to eliminate leakage in such wells. At the same time there are no universal and reliable techniques. The problem of well leakage is seriously increasing when wells are decommissioned (plugged and abandoned, P&A), and even more so when the development of the field is finished. The techniques of plugging and abandonment do not guarantee the integrity of the abandoned wells for centuries. Obviously, then the abandoned field would become the object of a local ecological catastrophe. As the development of all oil and gas fields is completed, the Earth will enter the era of the Global Environmental Disasters. In this article authors propose innovative techniques and technical solutions for sealing procedures and plugging and abandonment operations on wells.

1 Introduction

In 2016, the UN approved its long-term Program for resolving urgent problems until 2030. It identifies 17 of the most important Goals with reference to our civilization. By rights, 5 of the global Goals are somehow related to environmental problems. In his article [1], Ban Ki-Moon highly appreciates, in particular, the environmental aspects of this Program.

Oil and gas blowouts when drilling wells usually cannot be associated with the problem of their leakage, because human factor is the negative reason here. But the unique blowout in the Gulf of Mexico (Mocondo well) in 2010 is the result of loss of well integrity. Unfortunately, such an individual, particular tragedy has become an All-Planetary one (Figure 1).

Individual, local catastrophes associated with well leakage are not brought to the public. Therefore, a publication in an industry journal [2] deserves attention, apparently accidentally found on its pages.

A group of ecologists received for their study a certain territory at an ordinary field «N» under development. They drilled 15 parametric wells with depths in 50 to 70 meters range. In soil samples, 20-times the maximum permissible values for oil saturation were detected.

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In Fig. 2 from [2], environmentalists show oil-contaminated water sources. As for the karstic cavities, they were also filled with oil.

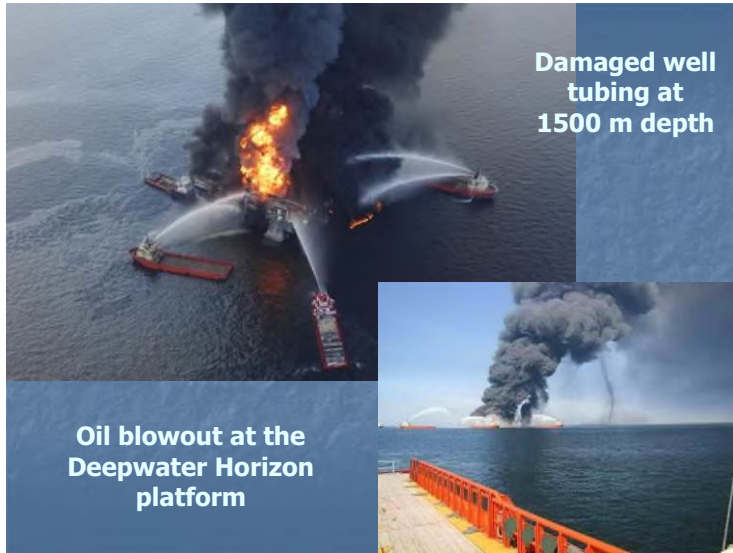


Fig. 1. Fire extinguishing on the Deepwater Horizon platform.

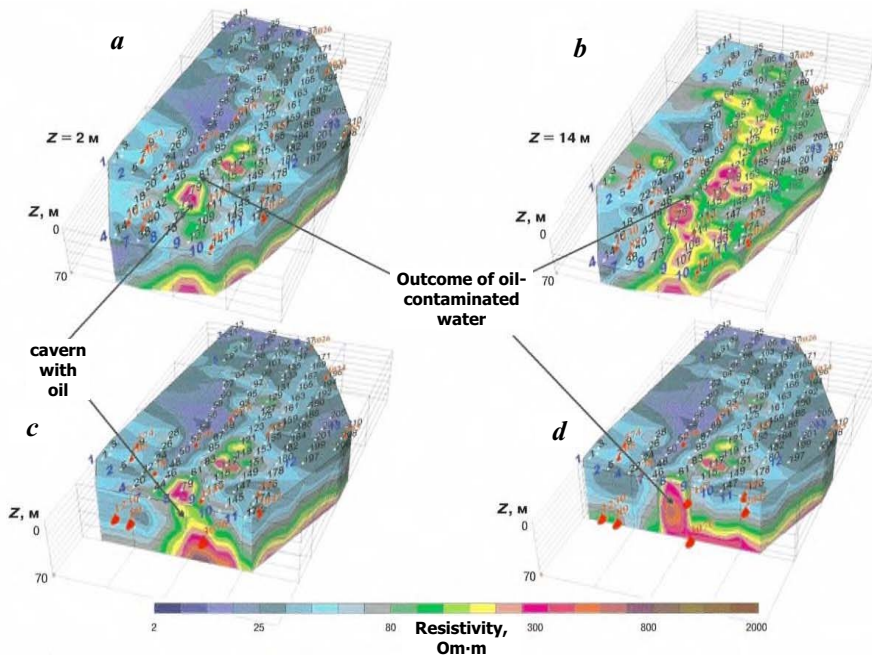


Fig. 2. Oil-contaminated sources of water supply and karstic cavities [2].

It follows that during oil production, not only the surface soil and aquifers are often polluted, but also significant subsoil volumes below the earth surface are also exposed to contamination. The above examples serve as a demonstrative basis for further discussion.

The fundamentals and practice of oil and gas production still cannot cope with the appearance and elimination of leaks even at majority of operating wells, with a lifespan of 5-

10-15 years. What to say about the abandoned wells with a much larger age (potentially infinite).

A subsequent major technogenic problem has not yet been recognized by the UN members. Oil and gas deposits, as already mentioned, are developed on the basis of production, injection, control, piezometric wells. It is known that these are complex, expensive mining and technological facilities. Not always a drilling crew is experienced. Also unforeseen natural, geological factors predetermine low quality of wells, including emergency situations, blowouts, and human victims.

The development of oil and gas fields often has a negative impact on the Environment. Breaks of infield and main oil and gas pipelines, tanker accidents are endless. They are sources of pollution of soil, rivers, lakes, oceans, air. Contamination of artesian wells, for example, in the Ural-Volga region (Russia) resulted in the supply of water to the population in truck tanks. The problem of high quality water supply is now relevant in the US, for example, due to the shale oil and gas production.

After completion of drilling, each well undergoes a leak test. The relevant procedures are documented in the well datasheet. That is, leakage occurs in the process of well operation.

Numerous are the reasons for leakage in production wells. These are poor-quality cement, unsatisfactory cementing procedures, loss of casing integrity due to, for example, corrosion, perforation, tectonic movements, periodic moon attraction, temperature deformations, alternating loads in underground gas storages.

Although monitoring of well performance is ongoing, leaks are not determined always and immediately. Subsoil users do not advertise the situation with leakage, and even more so – its consequences for the subsoil and the environment.

This situation does not facilitate accumulation of experience in combating leakage and advancement in research on the improvement of technics and technologies for plugging and abandonment. Individual monographs mainly record the sad facts of leakage [3], without serious research to eliminate the problem of leaks itself.

One well in the Gulf of Mexico caused a Planetary Environmental Catastrophe. There were quite many such Catastrophes in history. If we do not tighten control over this problem, then in the near future we will all face the World Ecological Catastrophe (WEC). There are up to some million abandoned ownerless wells only in the US. For instance, the authors of [4], [5] and [6] provide a lot of examples of problems with integrity of wells in the US and with the situation around plugging and abandonment procedures.

2 Methodology

Conventional plugging and abandonment procedures on wells in Russia are as follows. The tubing with the well pump is removed from the well. Then, with periodic cement injection, two bridges (plugs) are created (see Figure 3). At the well head, a plug and a concrete pedestal are installed (Figure 4) [7].

After plugging, corrosion processes begin (continue) in the well. The well is subjected to tectonic, seismic influences, the attraction of the Moon. These processes negatively affect cement bridges, as well as cement in the annulus of wells. As a result, they are destroyed and the integrity of the well disappears.

Oil (gas) remaining in the reservoir enters the well annulus and then penetrate into the overlying aquifers and artesian beds, resulting in their contamination. Through the casing, oil and gas come to the surface in the form of a blowout of some power or other, with corresponding negative consequences.

An example with the Tengiz field in 1985 may, if not a single case, characterize the considerable possible consequences.

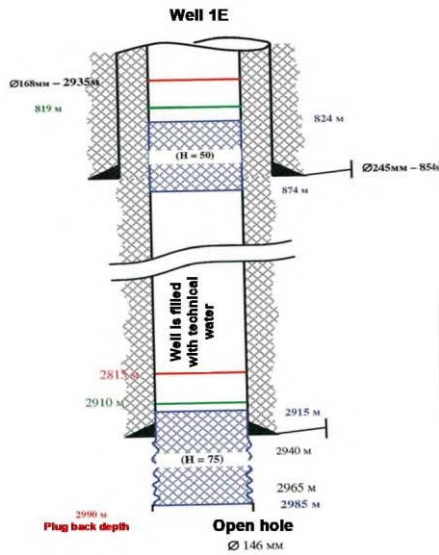


Fig. 3. Schematic of cement bridges installation during plugging and abandonment of a well [7].

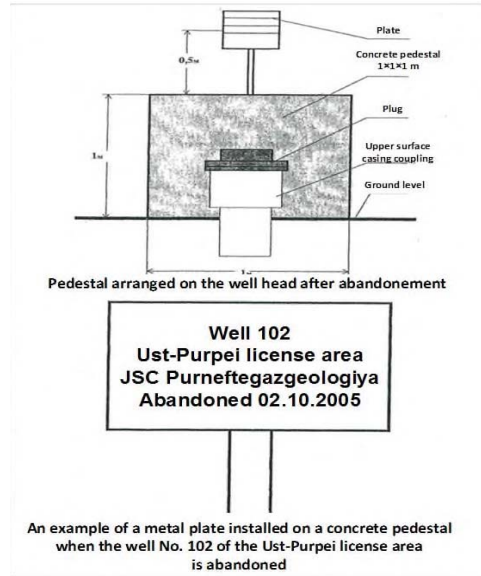


Fig. 4. Schematic of well head capsulation during plugging and abandonment of a well [7].

After the discovery of the unique Tengiz field, there was a powerful oil blowout at well # 37 [8]. The well flared for more than a year. Every day, at least 10 thousand tons of oil with H₂S in associated petroleum gas were emitted into the atmosphere. (And such a field is not unique on Earth). Let's say that after 30 years, when the economic limit will be reached, the development of this field will be completed. And after 50-60 years the initial reservoir pressure of 800 atm (~80 MPa) will be restored. Petroleum gas dissolved in Tengiz oil contains 16% H₂S. Due to corrosion and other causes, the wells will begin to gush.

We do not even start discussing the problem of blowouts in abandoned wells with subsea completions in ice-free seas, after commissioning of the parent platforms. We could face even more horrible possible blowouts on similar wells in the Arctic shelf. But today the development of oil deposits in the Arctic are associated with high expectations. For the authors it is difficult to imagine the situation of managing a blowout at a well under a bed of ice, for oil would outflow uncontrollably in the ocean under the ice coating. There is no technology of well abandonment (decommissioning) on the Arctic shelf. From our point of view, it is necessary to put a Moratorium on the development of oil and gas fields on the Arctic shelf.

Petroleum industry in the US and Europe is more than in Russia concerned about the problem of plugging and abandonment, especially for wells drilled on offshore platforms. Therefore, from time to time, results of the corresponding R&D (research and development) studies are published. As an example, one of the publications [9] describes the procedure for plugging of a well with the use of plasma equipment (see the upper part of Fig. 5). With the help of the plasma device, part of the casing string, the cement ring in the annular space and a part of the adjacent rock are milled for further removal (the lower part of Fig. 5). Then a cement bridge over the whole cross-section of the well is installed. Yes, it's a very exotic, but difficult-to-implement and expensive technology. However, it is important that such R&D studies take place.

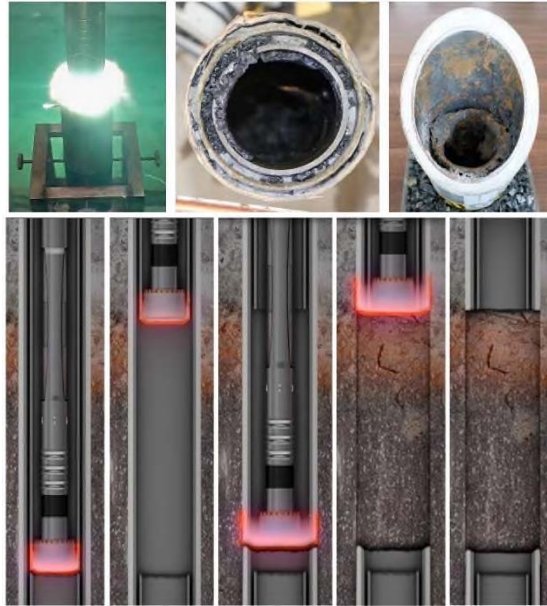


Fig. 5. Test studies of the plasma tool for milling and removal of a part of the casing string and the cement ring before cement bridge is installed during well plugging and abandonment [9].

A few words about the replenishment of hydrocarbon reserves and energy in the abandoned oil and gas fields. These factors determine time to possible blowouts and their negative intensity.

The replenishment of oil and gas reserves is no news by now. However, for various reasons subsoil users do not advertise relevant facts. For instance, it is necessary to recalculate hydrocarbon reserves, approve them in the regulatory authorities. We refer to only a few publications [7, 10]. In these studies, inflows, for example, of oil are identified by changes in the composition of produced oil, or by accumulated oil production of individual wells that exceeds the specific reserves associated with these wells.

One of the main reasons for the non-universal acceptance of the presence of oil (gas) inflows is that these facts are difficult to be established and evaluated. In addition, the subsoil user does not desire to spend money on the relevant studies.

Authors on the example of the Shebelinskoye gas-condensate field (Ukraine) managed to identify and take into account the phenomenon of replenishment of gas reserves in figures [10].

The attractiveness of this example is that it was developed under the gas drive, that is, without the inflow of formation water. As a result, on the one hand, the authors managed to determine that for gas production from the field of about 2.5 billion m³/year, the average reservoir pressure would not decrease. That is because the inflow of additional gas into the reservoir compensates its production. Based on this result, the subsoil user was given the following recommendation in 1999: «...If 2.5 billion m³/year of gas would be produced from the Shebelinskoye field, the deposit would turn into a “perpetuum mobile”...»

According to Fig. 6, it turned out just so in the time interval available to the authors, albeit with slight deviations from the recommendation.

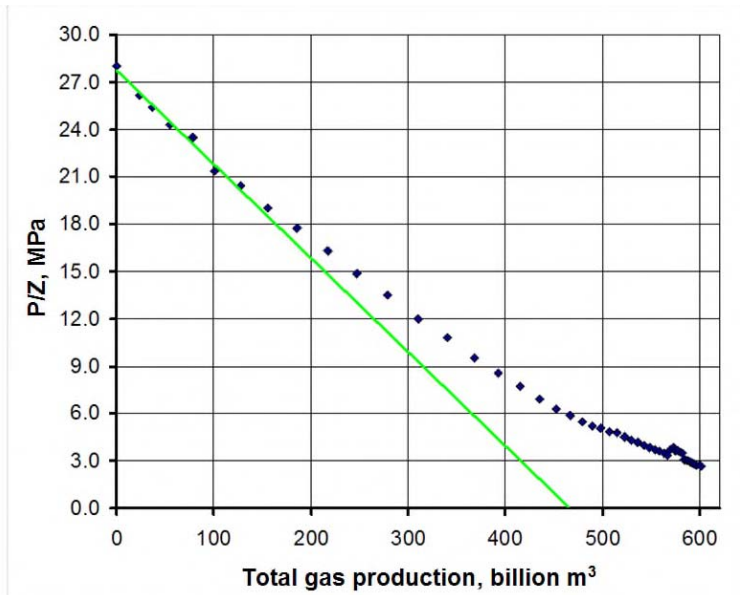


Fig. 6. Dependence of reduced pressure on cumulative gas production for Shebelinskoye field.

For the initiation of blowouts, big or small, in the abandoned fields, inflows of oil and gas are not required. According to numerical experiments [10], secondary oil deposits are formed from the remaining oil in the reservoir only due to segregation processes. And due to the inflow of formation water in such a reservoir, the reservoir pressure is restored. These two factors are sufficient for various negative consequences.

Also important is the published data of the research study at Lobodice underground storage facility in the Czech Republic during injecting and production of the town gas [11]. In the injection cycle, the gas contained 55% H₂, 20% CO₂ + CO, and 20% CH₄. After several months of storage, the produced mixture was characterized by the composition of 37% H₂, 12% CO₂ + CO and 40% CH₄. Subsequent analysis showed that part of the CH₄ produced is isotopically different from the injected methane. The authors of the paper [11] explain the increase in the yield of CH₄ and the change in its isotope composition by the action of methanogenic bacteria.

Each oil and gas reservoir has its own roof, called the sealing horizon, or the cap rock. So if it is not solid, then no deposit would initially be. And if it is leaky, the contents of the deposit migrate into the overlying layers, up to the earth's surface. Naturally, with oil polluting the flow paths, and even the biosphere.

This is to the fact that now there is a rage for large-volume and multi-stage fracturing (hydraulic fracturing of the reservoir). It is necessary to know and remember that the fractures of any hydraulic fracturing are primarily directed towards the top of the reservoir. It is especially critical if the thickness of the reservoir is low. Apparently, in a considerable number of cases there may be a disintegration of the cap rock of the reservoir, followed by the dissipation of reserves of the deposit, with smearing of migrating oil and gas in the overlying horizons – in vertical and lateral directions. Unfortunately, in shale oil reservoirs, cap rock is often not present at all!?

No wonder a number of US states have prohibited multi-stage hydraulic fracturing. That is because a momentary increase in well flow rates can turn into a considerable loss in the accumulated volumes of oil and gas production, and obviously with negative environmental consequences.

3 Results and discussion

For solving the problematic issues discussed, we present novel technological ideas for well sealing during completion and P&A..

For further presentation of the technology of well completion during drilling, let's turn to the scheme of well bottomhole layout shown in Fig. 7. This unconventional layout was born from the transition from cement-based slurry to bitumen (tar) based.

The numbers **5** and **8** refer to the drilled rock. All the remaining free internal space at the end of the drilling process is filled with drilling mud (based on polymer or other chemical agents). The drilling tool has already been removed from the well, so it is not shown on the scheme.

The first operation to be performed is to lower the casing (housing) string of pipes number **1**. We note that usually there are 2, 3 or more such pipe strings, depending on the depth of a well, which ends at the bottom of the pay formation **7**. It is sufficient to discuss only the last casing, as technological operations for other casing strings are similar.

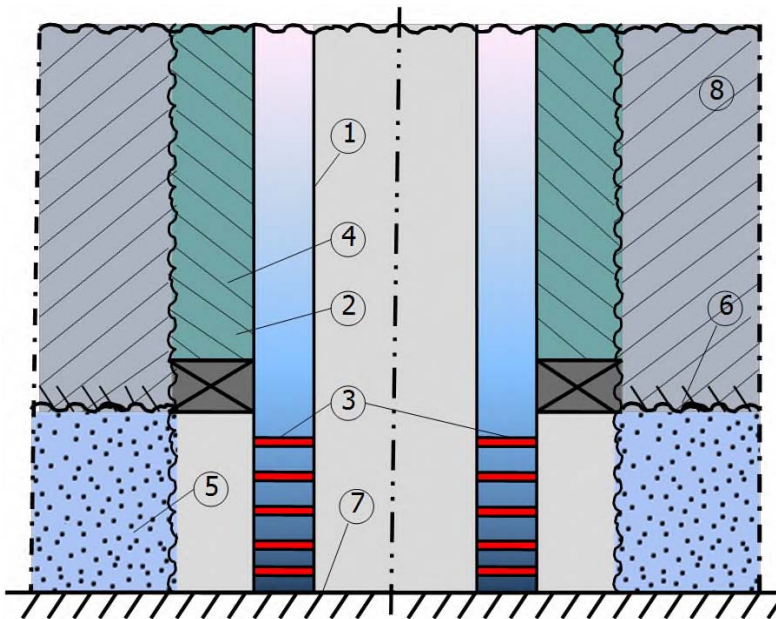


Fig. 7. Schematic of the well bottomhole layout (see text for details).

Unlike the conventional layout, a set of holes of 1-2 cm in diameter should be drilled in the lower part of the casing, from the bottom of the formation **7** to a certain mark below the top of the formation **6**. The well bottomhole can be below the bottom of the formation **7** due to the sump.

Another unconventional feature of the casing **1** is that an external packer **2** should be attached to it at the top of the formation. Up to a certain point, which will be discussed later, the packer remains closed (unsealing).

The second operation consists in removing the drilling fluid from the inner and annular spaces of the casing. For this, nitrogen is pumped into the annulus from the wellhead. Nitrogen displaces the drilling fluid in the top-to-bottom direction from the annulus, past the closed (unsealing) packer, and through the holes **3** – from the inner space of the casing to the wellhead. The injection of nitrogen continues until it appears at the wellhead with no signs of the drilling fluid.

After that, the packer **2** is opened (set sealing) to separate the annulus above and below the packer. From this moment, nitrogen from the annulus is discharged, for example, into the atmosphere. With the wellhead pressure coordinated with the formation pressure, a sealing agent is fed to the annulus. Liquefied tar, bitumen or bitumen composite serves as the sealing agent. The feeding is carried out in such a way that part of the annulus at the wellhead remains open to allow for exit of the nitrogen being replaced by the sealing agent.

During the feeding of the sealing agent, the temperature in the annulus is maintained at the required level by heating the casing by electricity or by circulation the heated water (or other heat-transfer liquid) inside the casing. Circulation of the heat-transfer liquid is carried out by lowering the coiled tubing (a string of flexible pipes) or another column of pipes of smaller diameter (for example, the tubing string) into the inner space of the casing. The temperature control with depth in the annular and inner space of the casing is carried out by thermal sensors.

After the sealing agent has hardened in the annular space, a tubing string with a downhole pump or other downhole assembly is lowered into the well, and the production of oil is started.

The mentioned sealing agents are not absolutized, since thermobaric conditions and other factors at different petroleum fields are not the same. For the same reason, it is not ruled out that in some cases a certain adjustment of the applied technological operations will be required.

Advantages of the proposed completion technology are as follows.

1. According to conventional technology, cementing of the annular space is achieved by pumping a cement slurry from the wellhead into the casing (which is usually lowered to a level not reaching the bottom of the well). Cement slurry is forced into the annular space almost to the wellhead. Well testing and well logging data show that cement integrity is not always achieved. Therefore, additional, costly technological solutions are required to eliminate leaks. The proposed liquefied sealing agent, due to its consistency, will be more evenly distributed within the annular space. And also, due to the higher (and adjustable for the bitumen composite) adhesion to the surface of the rock, it will create a more reliable contact with it. And in the case of the conventional injection of cement slurry to a height of 1000 to 5000 meters and more, it is difficult to expect its perfect distribution in the annulus.

2. With the conventional technology, due to the cementing operation, a cement slurry penetrates into the near-wellbore zone of the reservoir. To achieve the connectivity of the reservoir with the well, expensive perforating operations are performed. However, they only partially restore the natural (possible) connectivity of the near-wellbore zone with the well. Such a negative factor with the decrease in the productivity of the well is absent in the presented technology.

3. The technology does not require expensive perforating operations. This is important because the perforating operations also affect the integrity (sealing properties) of the cement stone in the annular space.

Perforating operations are usually carried out with a working liquid agent in the casing which is foreign to the formation fluid (oil or gas). It is known that this strongly reduces the permeability of the near-wellbore zone for oil, and hence the oil production rate. Perforating operations are usually accompanied by pipe lifting operations, which also worsen the reservoir properties in the near-wellbore zone. These technical and technological shortcomings are not inherent in the presented technology.

Plugging and abandonment operations on wells leaving production, injection stock, and others are also part of the problem under consideration. Now, therefore, we consider wells completed using the technology just described. Accordingly, the bottom-hole layout remains the same. And downhole equipment (such as a submersible pump) at the time of the plugging operations is already removed from the well.

In the proposed plugging and abandonment technology, heating of the sealing agent (tar, bitumen or bitumen composite) in the annulus is first carried out until an acceptable level of its mobility (viscosity) is achieved. Almost simultaneously, the casing string is cut slightly above (10-20 cm) the external packer with a cutter or a sandblast tool. The casing is removed from the well, and the liquefied sealing agent acts as a lubricant. Casing pipes are transferred to the appropriate plants for recycling and producing new pipes. The liquefied sealing agent is continued to be pumped into the former annular space until the drilled well volume is filled with the sealing agent.

A moderate pressure is then applied at the wellhead for consolidation of the sealing agent in the drilled well volume. After cooling and hardening of the agent, a pedestal and a plate with the well number and information on the subsoil user are installed at the wellhead.

The recovered casing gets a "second life", which also has some environmental benefits. The extraction of iron ore is reduced, due to the decline in the demand for steel in the world. The energy demands are reduced during transportation of ore and its processing. Energy saving at all stages entails a reduction in the demand for oil and gas production, which combustion is necessary at various involved facilities.

An abandoned well without metal inside its volume is no longer subjected to corrosion processes. A reliable seal against the possible inflow of oil and gas from the reservoir is guaranteed by a "tar plug" at the bottomhole and along the drilled wellbore. The well becomes an "integral part" of the surrounding rocks with practically zero porosity and permeability of the sealing plug. In addition, owing to appropriate viscoplastic properties of tar / bitumen composite, the possibility of formation of discontinuities (cracks) in the plug is minimized, and their self-healing is ensured in case they nevertheless arise.

4 Conclusion

The two technologies described (for well completion and plugging) will be appropriate for newly drilled wells.

Unfortunately, there is a huge amount of abandoned wells, completed when drilled and plugged when abandoned by conventional technologies. For them, the first technology is no longer needed. And the second technology, respectively, cannot be applied, because tar-like sealing agent was not used during drilling.

Therefore, in all such wells, annual monitoring of wellhead pressure should be organized. Wellhead pressure will be a measure of the intensity of replenishment of oil and gas reserves in an abandoned field, and hence of the corresponding reservoir pressure.

In the case of an intensive increase in wellhead pressure in such a well, pressure should be released also in the near-wellbore zone. Subsequently, the heated tar or other sealing agent is pumped into the well. Due to its highly permeating nature, the sealing agent will fill holes in the metal from corrosion, cracks from tectonic movements, etc.

It is difficult to restore the past here, but vigilance on such wells and fields is needed, since it will be, on the cheap, by means of pumping the sealing agent, the guarding element on the "environmental front".

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