Study and Practice of stabilized injection technologies in injection well life cycle

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Abstract. The technologies to steady pressure and injection rate and that to reduce pressure and increase injection rate are along with multiple stages of secondary and tertiary oil recovery. The ongoing injection process will subject most wells to pressure rise, reduced injection volume, fouling and plugging of reservoir, and corrosion of tubing string. In this paper, a portfolio of feasible measures can be provided for the steady injection in injection well life cycle by taking a closer look at cleaning & anti-swelling & anti-migrating technology, interlayer pressure influence balancing technology, slow releasing solid acid unpowered acidizing technology, low damage & low reaction rate acidizing technology, and degrading & acidizing technology for polymer injection wells.

1. Introduction
Fossil oil is a non-renewable fossil energy buried underground, only 8-15% of the oil reserves can be recovered by natural capacity. For complement to formation capacity and improvement of displacement efficiency, it is essential to perform secondary oil recovery (manual water and gas injection) and tertiary oil recovery (chemical oil displacement) by injection well, so that the oil recovery ratio can be enhanced [1].

The injection well life cycle consists of the introduction period, during which the configuration of well pattern is decided, the reservoir connectivity will be analyzed and predicted; after injection, the needs for reservoir injection are fulfilled by change of injection allocation, well washing, fracturing, acidizing, profile control and other options. The steady injection technologies in injection well life cycle are based on the observation of reservoir connectivity and sensitivity, consisting of target layer cleaning, anti-swelling, steady pressure and injection rate on the target layer, measures to reduce pressure and increase injection rate, interlayer pressure influence balancing technology among other technologies, so it can be applied in multiple stages of the injection well life cycle.

2. The technologies to steady pressure and injection rate
Under the influence of reservoir minerals, injection well may be vulnerable to different degrees of clay swelling after injection. Due to quality of injected fluid, compatibility, temperature and pressure change, fouling is very likely to happen in the wellbore and in the vicinity of wellbore, which may clog up the reservoir and corrode tubing string. As a result, the injection pressure will increase and the injection volume will reduce [2].

2.1 Cleaning & Anti-swelling & Anti-migrating technology
Clay swelling, dispersion or migration would lead to a substantial drop of water absorption, so the injection rate would effectively increase if the clay swelling can be prevented in the injection process
The preferred selection evaluation of anti-swelling agent is carried out based on the analysis of the core sensitivity experiment. The anti-swelling agent suitable for the reservoir rock is preferably selected by performing an evaluation of the anti-swelling rate of block cuttings and bentonite, and of the damage rate of block core. Crude oil emulsion can emulsify plugging and adhesion in the pore medium, which is likely to retain drops in the pore medium. With an extremely high dynamic viscosity, emulsion can drastically increase the fluid flow resistance in the reservoir. And the high carrying capacity allows it to enhance the particle migration in the reservoir pores and increase the plugging of the seepage channel.

| Item                  | Technical Parameter |
|-----------------------|---------------------|
| Anti-swelling rate    | ≥85%                |
| Core damage rate      | ≤5%                 |
| Long-term damage rate | ≤10%                |

The pressure rise of injection well in the initial period of injection can be primarily explained by the clay swelling and migration as a result of the reservoir sensitivity and the incompatibility of injected fluid quality. The cleaning and anti-swelling pretreatment, a technology used in the initial period of injection, can prevent clay swelling and reduce the damage on reservoir by injecting treatment fluid and suppressing the diffused double layer effect (utilizing the principle of polymer-ion exchange). This technology can further clean the residual oil in reservoir and prevent the crude oil in the porous medium from emulsification (otherwise the permeability ratio of the reservoir may reduce), so that water will be injected at a long-term steady pressure.

From the comparison of Well Z4-24-5 and Well Z4-24-1 in the same block and with similar geological conditions, the injection pressure of the well untreated with cleaning and anti-swelling will rise at a rate twice of the untreated well in the first month of injection.

A validity period is imposed on the use of anti-swelling measures in injection well. As injected water goes deeper, the capacity to prevent clay from swelling and migrating will decrease bit by bit, some rock minerals in the reservoir would migrate and clog the pore throat, resulting in oil pressure rise. In a natural core treated with anti-swelling and anti-migrating, nanoparticles will adhere on the rock surface. As a consequence, the release area between rock and water phase will reduce, the scouring capability of water flow on rock particles will weaken, and the displacing fluid particles and the median particle size
will significantly reduce after displacement.

Figure 3. Natural core treated with anti-swelling and anti-migrating to reduce the damage from particle migration

The cleaning & anti-swelling & anti-migrating technology is essential to maintaining the long-term injection at a steady pressure. With an ongoing process of water injection, the dosing cycle is simulated at an interval of 3-5 months according to the pressure and injection condition. Anti-swelling agent is added in the injected water for continuous anti-swelling, which can lead to a slowed rate of oil pressure rise in injection well by 58%.

2.2 Interlayer pressure influence balancing technology
There is an interlayer pressure difference in the waterflooding development of heterogeneous reservoir. When the bottom-hole pressures applied on two layers are identical, the pressure of high permeable layer rises at a higher rate than that of low permeable layer in the vicinity of the bottom-hole zone. As a result, there is an interlayer pressure difference in the vicinity of the bottom-hole zone. According to the theoretical calculation, the interlayer pressure difference is up to 100 kg/cm² when the difference of layer-to-layer permeability is 10 times [6]. Interlayer interference means small layers with different physical properties are restricting and influencing each other in the waterflooding development, especially for reservoirs whose permeability ratios are vastly different. More specifically, the reservoir with lower permeability ratio is found with lower displacement rate and more difficult displacement, vice versa. This phenomenon leads to premature water breakthrough in oil-producing well on the well-connected high permeable layer, which in turn causes water flooding.

In case of interlayer pressure influence balancing technology, a surfactant nanomaterial is injected to reverse the wettability of formation rock and change the property of formation rock from hydrophilic to hydrophobic. As a result, the seepage capability of high formation will be enhanced, thus improving the outcome of waterflooding development. Moreover, surfactant can reduce the wetting angle, so the residual oil in reservoir is less restrained on the rock surface. The thin film of oil is ruptured under scouring action, reducing the proportion of non-flowable residual oil, increasing the seepage velocity of oil. This is supported by an increase of fluid production volume and a decrease of injection pressure in producing well. Surfactant can cause the meniscus in the formation capillary to be deformed, accompanied with an increased number of flowing capillaries. Consequently, the injected water wave and volume will expand, the recovery rate and injection efficiency also increase, the injection loss per unit of oil production will reduce after the application of surfactant [7].

3. The technologies to reduce pressure and increase injection rate
In injection well, poor quality of injected water may cause fouling, clay swelling and particle migrating may clog up the pore throat, which leads to rapid increase of injection pressure and adversely impact the outcome of waterflooding. Acidizing provides a critical measure for defouling and unplugging, reducing injection pressure, and restoring injection volume. The acidizing experiment on field water samples affirms that many solid suspended solids are contained in field samples, water impurities mainly consist of oil fouling and inorganic impurities. Acid etching can remove a lot of impurities, so acidizing is one of the better measures for defouling and increasing injection rate.
3.1 Slow releasing solid acid unpowered acidizing technology
The weaknesses of regular acidizing process include unaffordable operation cost and long construction period. Especially for separate injection well, it is more difficult to implement this process. In addition, regular acidizing process is very likely to contaminate the hydrochloric acid-sensitive reservoir. Slow releasing solid acid unpowered acidizing technology is proposed specifically for steady pressure and injection rate at an affordable cost without moving tubing string. This proposed technology is expected to improve water quality and prevent fouling from contaminating the reservoir in the long run.

Inert or slightly corrosive solid acid has obvious strengths when applied in the area of safety and environmental protection. Slow releasing solid acid is composed of water-soluble gel slow releasing skeleton, solid acid, corrosion inhibitor and other components, which can slightly dissolve rock cuttings and enhance the function of the formation pore throat; as slow releasing solid acid is slightly acidic and has a limited capacity to dissolve the formation, it would not cause the formation to collapse. Slow releasing solid acid is associated with salinity of injected fluid, reservoir temperature, flow velocity and fluid contact area. At 60°C and under the flow velocity of 0.1 L/min, the release rate of solid acid can be measured by detecting the cumulative acid content in flowing fluid within a certain time. The dissolution time of slow releasing solid acid would reduce as the temperature rises or as the flowing velocity increases. Results show that the acid release rate would increase as the temperature rises; at 60°C, the mean release rate of solid acid active substances within 10D is 21.6 g/d.

To extend the duration of injection process and reduce unaffordable cost, hazards and construction complexity due to regular measure of increasing injection rate, slow releasing solid acid is compacted to a cylinder shape. During the injection period, the solid acid cylinder is put into the wellbore or a basket outside the tubing. Without stopping the injection process and using any powered device, acidic active substances can be slowly released and the water flowing to the formation has some acidity, unplugging and defouling in the vicinity of wellbore.

The injection pressure is found without significant change within 1 year after the slow releasing solid acid unpowered acidizing technology is applied on Test Well H101. In contrast with the reservoir with similar lithological character and sensitivity (Well H105), the pressure relief rate increases by 90%. Therefore, this measure can achieve the purpose of steady pressure and injection rate.

3.2 Low Damage & Low reaction rate acidizing technology
Sandstone reservoir is usually acidized with hydrochloric acid and hydrofluoric acid. Hydrofluoric acid can simply react with siliceous or carbonate rocks in the matrix, but its reaction with silicates such as clay or feldspar tends to be highly complex. Hydrofluoric acid can react with most components (quartz, feldspar, clay, carbonate) in sandstone at different rates, the reaction products are likely to generate insoluble fluoride precipitates that may clog up the pore throat. Regular acidizing process is performed on the low permeable reservoir, most of the acid active substances are consumed in the vicinity of wellbore. As a consequence, the acid modification distance is shortened, no effective flowing channel can be established, ultimately leading to a shorter validity of acidizing measure and a higher rate of pressure rise [8].

Under any condition, Fluoboric acid does not contain a large amount of hydrofluoric acid, which means it has low reactivity. The hydrofluoric acid in fluoboric acid solution will produce many hydrofluoric acids by hydrolysis when consumed. Therefore, its total dissolving power is comparative to mud acid. Fluoboric acid can be used as a pre-flush before the treatment with mud acid (sensitivity formation), which can avoid particle instability and subsequent pore plugging; alternatively, it can be used as a subject acid for sandstone matrix or the formation which contains many clay minerals. The low damage & low reaction rate acidizing technology, coupled with other additives and treatment fluid system, is applied in multiple sandstone reservoirs including B24-15. After the measure is taken, the mean pressure drop is 14% and the average increase of injection volume is 30m³/d.
3.3 Degrading & Acidizing technology for polymer injection Wells

The under-injection of polymer injection well is primarily caused by polymer plugging. When the permeability ratio of the core exceeds $1000 \times 10^{-3} \mu m^2$ and the concentration of sample with fouling is 0.1mg/L, the permeability loss as a result of polymer adsorption and retention is up to 20%-30%. Its plugging substances contain many components such as polymer floccule, clay, mechanical impurities, calcium and magnesium scales, so it is hard to identify the exact type of components [9]. In the vicinity of wellbore, the pressure gradient is found with a substantial change; within the zone away from wellbore, the pressure gradient is found with a steady change, suggesting that the retention and adsorption of polymer in formation within the zone away from wellbore tends to be balanced. Furthermore, no obvious plugging of polymer flow will occur within the zone away from wellbore with the increase of polymer injection time, but plugging usually occurs in the vicinity of wellbore. As proved by several practices made in the initial stage, any unplugging technology with a single function is incompatible with complex types of plugging. Moreover, the technologies associated with polymer unplugging are not fault-free, leading to unobvious outcome of unplugging and a short period of validity.

![Figure 4. Construction process flow of degrading & acidizing technology for polymer injection wells](image)

The degrading & acidizing technology for polymer injection wells exploits the cooperative action of polymer unplugging agent and acid liquid to get the wellbore fouling completely treated. Degrading liquid is used to unplug wellbore and the seepage channel in the vicinity of wellbore. With continuous injection at a low rate and multiple pumping stops, this measure can degrade polymer and dissolve polymer micelles. In the meanwhile, the Polymer coating for rock and mechanical impurities is stripped off. In doing so, acid liquid can fully dissolve the exposed sand and clay minerals, expand the pore throat, unplug carbonate and silicate minerals, and avoid reservoir plugging and secondary packing due to subsequent particle migration, allowing for deep and longstanding chemical unplugging.

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References

[1] Wu J., Chang Y.W., & Yi J.X., et al. Maturity analysis of oil exploration and development technologies [J]. Science and Technology Management Research, 000(024):24-27.
[2] Yuan W.H. Experiment and study of factors influencing injection in low permeable reservoirs[J]. Chemical Enterprise Management, 2017(25):209-210.
[3] Chen Y., Meng J.H, Gao M., He X.H., & Cao Q.L. An integration application of injection process technologies to stabilize the oilfield production in later period of high water-cut development[J]. Inner Mongulia Petrochemical Industry, (3):125-127
[4] Li X.W.& Wang D.M. Influence of oil emulsification on permeability ratio of the formation[J]. Oil-Gasfield Surface Engineering, 2004(5):12-12, 12.
[5] Ren K.F., Shu F.C., Lin K.X., & Luo G. Study on the Technology of Composite Nano Depressurization and Augmented Injection for Water Injection Well in Offshore Oil Field[J]. Offshore Oil,2016,36(4):61-64.
[6] Zhao Y.S. Interlayer interference of injection wells[J].Exploration And Development, 1983(01):64-69.
[7] Ma J.G., Li X.Q., & Miao H.W. An overview of new chemical additives for augmented injection[J]. Xinjiang Petroleum Science Technology, 2007(02):29-30.
[8] Zhang L.M. Several selection principles of acid liquids and additives for sandstone acidizing in
overseas practices[J]. Chemical Engineering Of Oil And Gas, 1993, 022(002):103-107.

[9] Meng X.L., Zhao L.Q., & Xu K. et al. Reason analysis on plugging in polymeric damaged well and the technology of broken down[J]. Oil Drilling & Production Technology, 2011, 033(003):70-73.