Analysis on Seal Test for Polymer Injectors with Shuttle-shaped String

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Abstract: String seal integrity for layered well is the key factor to a successful development of polymer injector. Existing seal test method for water injectors has poor performance in the situation of shuttle-shaped string and encounters a low success of isolation jobs. Therefore, by analyzing the factors contributing to the seal integrity of shuttle-shaped string, gradually increasing testing time, changing seal test method and other test methods, to determine time taken for seal test in polymer injectors, and then work on the standardization of this practice can be continued to ensure performance of polymer injecting development.

1. Introduction
String seal integrity for layered well is the key factor to the successful development of polymer injectors. Pressure drop in polymer injectors is slow due to the property of polymer. The method of open-close-open for a serial of 5 minutes is a practice taken from water injector and it indicated that the seal test interval has no obvious pressure difference and the result was seal failure. This method could not properly explain the seal integrity in polymer injectors and in 2018 there was only a rate of 37.0% of wells that pass the seal test. Factors affect the seal integrity test of shuttle-shaped string are analyzed and field tests are performed to explore string seal integrity.

| Table 1 Statistical table of poly flooding wells in 2018 |
|---------------------------------|-----------------|---------------|-----------------|---------------|
| Section                         | Normal seal     |              | Homework seal   |              |
|                                 | Seal well (time)| Well Pass rate (%) | Layer Pass rate (%) | Seal well (time) | Well Pass rate (%) | Layer Pass Rate (%) | Seal Well (time) | Well Pass Rate (%) | Layer Pass Rate (%) |
| Water flooding                  | 117             | 36.8          | 41.1            | 60            | 56.7          | 62.0            | 177             | 43.5          | 48.3          |
| Poly Drive                      | 11              | 45.5          | 52.2            | 5             | 20.0          | 20.0            | 16              | 37.5          | 39.5          |
| total                           | 128             | 37.5          | 42.0            | 65            | 53.8          | 57.9            | 193             | 43.0          | 47.5          |

2. Seal integrity test principle and its affecting factors in polymer injectors

2.1. Seal test principle
Two commonly used methods of seal test are pressure gauge test in sealed layer and plug type pressure gauge test.
2.1.1. Seal test with pressure gauges in sealed layer

The typically used technique is the center passage seal test. Dual channel pressure gauge is installed in the sealed layer from bottom up to the top sequence on the waterflood flow regulator. After packer set, instrumentation tool is landed to valve seat to shut the center passage. Injection water head is applied on cross-section of the bleed valve through the upper conduct port. Therefore the cup is expanded to seal the mandrel center passage and then achieve the seal test of the selected layer. This layer is isolated from upper and lower sections of the tubing. By following a sequence of open-close-open at the wellhead and wait for 5 minutes for each operation, and then by checking if pressure above and below is change accordingly or not, the seal above waterflood flow regulator could be verified[1]. The string seal condition can be interpreted from its seal principle:

The first is the passage of the two pressure gauges are close. Packers shall be tight seal and the cup for the packer and element of the plug shall be adequately expanded to ensure no communication to oil formations.

The second is when there is a difference between tubing pressure and formation pressure, the seal testing formation should have water absorb capacity.

2.1.2. Principle of seal test with plug type pressure gauge

The plug type pressure gauge has the same shape of a normal plug. The normal plug in the watering injection regulator for the seal test layer should be removed and then a plug type pressure gauge is installed. The packing on the pressure gauge isolates the tubing and formation. There are two sampling points on the pressure gauge which are used for measuring formation pressure and tubing pressure. By open-close-open at the surface to change the operation mode and finally change wellbore pressure. If the pressure for formation is not changing with the tubing pressure, the packers above and below the pressure gauge are tight seal[2]. Compared to waterflood, similar seal test method is used for polymer injector. The difference is to stop pumping polymer before using water to do the seal test.

![Figure 1. Schematic diagram of sealing principle of sealing pressure gauge.](image)

However, there are certain difference between them. For the set type pressure gauge, the center passage is blocked due to cup expansion and thus the water could not flow from one layer to another layer, so for seal test, only the packer above the pressure gauge can be verified. The test has to be done layer-by-layer. While the plug type pressure gauge can be used for testing packers above and below it. Target testing layers are not necessarily one-by-one and fishing operation for nozzle are less than that of set type pressure gauge. One thing shall be made to avoid the nozzle being a dead one. For example, if there were 3 layers to be tested. Directly testing the second layer is enough (upper packer for regulator #1 could not be tested and it is no need to test the lower packer of regulator #3). If the second layer has seal integrity issue. It is required to test the upper packer and the lower packer adjacent to it. Seal test shall also be performed in the first layer and the third layer. But plug type pressure gauges should not be installed on regulator #2 and #3 at the same time. Because plug type pressure gauge is
similar to a blank nozzle and it could affect the seal test results.

2.2. Factors affecting seal test in shuttle-shaped string
Planning is proposed based on the key factors that affect seal integrity in polymer injectors by comparing the differences between polymer drive and water drive.

2.2.1. String component's effect on seal test
Shuttle-shaped string is currently used in polymer injection wells and comparing to water injector string, the regulator is relatively longer and the inlet is at a lower position. Conventional sealing test with pressure gauge fails due to short distance One of the two solutions for above issue is extending the distance by 21 centimeters between the cup and the hold down slips and this will keep the cup blocking the upper water inlet. The other solution is using plug type pressure gauge. String stress is relatively high in water injector when performing the seal test, the cup is expanding and adjustable nozzle is running into seal test layer. However, for polymer injector the plug type pressure gauge is used in the seal test and pseudo-seal-failure could occur because the upper and lower packing are easy to worn or damage during operation.

2.2.2. String debris's effect on seal testing
Polymer injector and subsequent water injector are all affected by the polymer. Sticky debris existing inside the string can easily cause seal test issues such as cup could not seal or outer packing of pressure gauge totally fall and tubing communicates to formation, pressures for both upper and lower section are changing accordingly. It could not determine if the seal test failure is because of the gauge not properly set or packer not functional[3]. This could not be observed on surface. By repeating the open-close-open method one more thime could help the pressure gauge to seal.

2.2.3. Injecting fluid’s effect on seal testing
Polymer has relative high viscosity and the pressure transmission of it is slow. Existing seal test using 5 minutes as observation time but for polymer injectors pressure changes is not obvious and there is no deviating trend of the two pressure gauges’ reading. The seal integrity could not be determined. To achieve seal integrity, longer transmission time is needed or just injecting water to accelerate the transmission speed shall be chosen. Statistics in 2018 shows layered pressure data of polymer injectors that by dropping 0.5 MPa it took more than 10 minutes and the less of the allocating volume, the less the pressure drop. Another factor that affect polymer injector operation is when shut in the well it is easy to hold up the pressure and cause bad effect on the polymer injecting pump. Due to this, seal test is chose to conduct by injecting water.

2.2.4. Inter-layer’s absorption effect on seal testing
Allocated volume for polymer is relative smaller and such layers have a lower pressure transmission speed due to its low permeability. In a short period of time there is no pressure drop, that will be a wrong information of poor seal especially in bottom layers with poor absorbing capacity. Moreover, when blanking nozzle is changed to adjustable nozzle, if there is scale that block the nozzle. Changes for no absorption exist and no matter the well is open or shut in, there will be pseudo-seal and impossible to verify the real situation[4]. Allocated injection volume shall be verified before the seal test. Volumes shall be recorded and pump pressure should be increased if it is necessary.

2.2.5. Inter-layer’s effect on seal testing
Layer thickness is small in polymer injector and there many situations of sub-interlayer.

3. Seal test in polymer injector
Because of above factors, the method used in water injector could not reflect the real situation of polymer injectors. It is necessary to perform seal test to find a reliable method for seal test in polymer
injectors.

3.1. Well selection principle for seal test
To avoid certain factors those are not necessary for the test, test wells candidate are polymer injectors which just completed and wells fail the seal tests. Completion job just performed for these wells and most of them have good seal performance.

There are three criteria: The first is wells with seal issues is completed in the year of 2019, The second is string should be shuttle-shaped, The third is wells should be polymer injector without sub-divided layers and no packer rubber in the well.

Based on above principles, we selected 20 wells with seal integrity issues to do the test.

3.2. Experiment of seal test method
Considering above factors, we bring the verification method as: Stop polymer injection and switch to injecting water, increase pump pressure for water injection, extend seal test time, change layer for seal test or change pressure gauges for seal test.

3.2.1. Increase injecting pressure
For wells with injecting pressure and fracture pressure above 3.0MPa, increase pumping pressure when performing seal test to increase the pressure difference. Furtherer this will increase the reliability of the test.

3.2.2. Gradually increase seal time
For seal test in single layer, the scheme for open-close-open changes from 3-5 minutes to 10 minutes and 15 minutes. By extending the seal testing time to ensure pressure fall-of time and separate the tubing pressure and formation pressure. This method has no obvious effect. Three wells went through the test and for each stage10 minutes was allocated, but from the results there is no indication of curve seal.

3.2.3. Repeatedly use of open-close-open method to assist packer setting
By repeating open-close-open method for single layer seal test, the surge pressure assists the setting of packer element or cups and there are two wells included in the test. One well has 2 layers. Allocated volume for first layer was 25 m³ and the second layer was 15 m³. Integrated testing instrument was used in the test. The first step was testing the 2nd layer by running in the adjustable nozzle. Initially normal test same as water injector was performed as open-close-open for 3 minutes alternatively and tubing pressure didn’t separate form formation pressure which indicate a seal integrity issue. When performing the same test again, the tubing pressure and formation pressure separated and passed the seal test. The reason of a success seal test for the second time was analyzed. Because the packer was not adequately set for the first time but the surge pressure from open-close-open again assisted the setting of packers.

3.2.4. Change layer for seal test
Running in the plug type pressure gauge to the layer with large injection allocation equivalent to absorbing layer is blocked, and under the same injecting pressure, the whole volume absorbed in the well well be reduced or even no absorption. The seal test layer has high permeability, high pressure loss and there should be a larger magnitude difference. If the packer seal is good, seal pressure difference is high and pump pressure at the injection station shall rise and volume shall be reduced. If the packer has a poor seal integrity, it won’t pass the seal test and pumping volume shall only have a minor change. Pressure and volume shall be recorded at the injection station when performing the seal test. Or it might needed to increased pump pressure.

One example is for a selected well with two layers, injection allocation for the first layer is 40 m³ and the second layer 60 m³. The second layer was confirmed with seal integrity failure in Sep 2019.
Seal test was performed again in Oct 2019. In the first round of the open-close-open operation, each stage lasted for 8 minutes, but for the last stage when open the well, it was over the fracture pressure, which is equivalent to running in a blanking plug and no formation absorption. If the packer seal fails, water could channel from #2 eccentric regulator to #1 and it won’t over the fracture pressure. This indicated that the packer between #1 and #2 eccentric regulator was working.

In the case where the lines of upper and lower pressure of the seal test instrumentation almost coincide with each other due to poor water absorption or non-water absorption, the method of slow opening and slow closing and prolonged time is used to perform string inspection, that is, to slow down the operation speed of opening and closing the well and extend it appropriately. The sealing time of this section can check out the qualified information. In addition, it is indicated for each seal test, it is necessary to contact the injection stations in time to verify the pressure and water volume changes, verify the water absorption of the surged layer, and prevent the impact of no water absorption between stations on the results of the seal.

4. Seal test for polymer Injector

4.1. Method
According experimental test results from above wells, the steps for seal test in polymer injector are concluded as follows:

- Stop injecting polymer and inject water for more than 2 hours.
- Increase water pumping pressure and injection allocation increase at least 10 m³. Record pressure and volume.
- If plug type pressure gauge is used for seal test and there is a well with two layers, check the packing condition of the gauge before running into either layer. Ensure there is no blanking nozzle in the testing layer and a scheme of open-close-open-close-open with time last 7-10-15-10-10 minutes shall be used to test the seal integrity. For a seal test conducted in a well with 3 layers, the plug type pressure gauge shall be running into eccentric injection regulator #1 and #3. If integrated instrument is used, change all nozzles to adjustable and follow the operation above.
- Record the volume of pressurized water in injection station when performing seal test. By doing this the affect of big changes of pressurized water volume in single well could be precluded.

4.2. Operation for wells with seal integrity issue
If seal test fails. Exam absorbed water volume for each layer. Change to another layer if there is poor water absorbing capacity in one layer. If there is a good absorption for the seal testing layers, change the pressure gauge and perform the seal test again and extend time for shut in and in a slowly open and slowly close manner[5]. If fails it is required to report to operation management to further check the condition of packer seal, debris in the eccentric hole or center passage.

4.3. Appraisal of seal test method
This method has been used to verify seal integrity of the rest 10 wells and 10 of them pass seal test with 16 layers sealed. Formation seal rate is 80.0% and there is an increase of 40 % than that prior to the verification. Which indicate the shuttle-shaped string has a better adaptability.

5. Conclusions

5.1. Factors contributing to the seal integrity in polymer injectors are: components in the working string, selection of testing instrumentation, derbies, type of injecting fluid, injecting volume for relative layers and existence of interlayer.

5.2. Low pressure differences between tubing and formation and low injection allocation volume can result pseudo-seal failure if inadequate seal fore applied. The correct method for seal test is: Stop
pumping polymer and injecting water for 2 hrs, increase pumping pressure and pumping at least 10m$^3$
of water. Extending time for each stage when repeatedly shut in and open the well.

5.3. Verify injection allocation volume for wells with seal integrity issues. Following cations also
needs to be performed: checking water absorbing amount for each layer, changing test layer, changing
out pressure sensors, extending layer shut-in time, slowly open/shut the well when performing seal
test.

5.4. Optimized seal test method in polymer injection well has increased job success rate up above 80%
and thus reduced cost due to wrong judgment and finally increase the performance of polymer
injection development.

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