Experimental Evaluation and Mechanism Analysis of Elastomer Failure Caused by Rapid Gas Decompression

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Experimental Evaluation and Mechanism Analysis of Elastomer Failure Caused by Rapid Gas Decompression

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Abstract: Gas dissolved in elastomer cannot release quickly and will expand dramatically when the pressure of surrounded gas environment suddenly released, resulting in gas bubble forming inside elastomer matrix and even rupture. The phenomenon is called rapid gas decompression (RGD) or explosive decompression (ED) failure. However, the research of gas especially acid gas effect on elastomer mainly focus on corrosion caused by chemical reaction. The RGD failure is mostly the result of physical action. In this study, the CO₂ RGD resistant property of NBR elastomer material used in CO₂ flooding downhole packer and PC pump was lab tested in accordance with operating condition. The failure critical point and appearance features were observed. And volume change behavior during pressurization, stabilization, decompression, and post decompression was also monitored. The elastomer RGD failure mechanism was analyzed. The research result provided solid foundation for service life prediction and selection of elastomer under high pressure and high CO₂ gas content conditions.

1. Introduction

At present, Daqing Oilfield has carried out field tests of CO₂ flooding to enhance oil recovery in Yushulin and Hailar blocks. Due to the heterogeneity of reservoir and viscous fingering of CO₂, it is easy to break through from zones with high permeability. Downhole pressure and gas oil ratio in production wells change periodically with the gas and water alternating injection in corresponding injection wells. Under special conditions, dramatic pressure change occurs in a short time resulting in frequent bubbling and blistering failure of downhole elastomer sealing components, such as packer’s cylinder and O-ring, PC pump’s stator. The research of gas’s effect on elastomer mostly focuses on the degradation caused by chemical corrosion reaction of acid gases [1-3]. However, some experiments founded the physical damage after high pressure test, they stated that the internal voids and cracks were caused by gas dissolution during pressurization stage rather than in decompression and post decompression stages [4]. This study simulated the physical damage appearances feature of NBR elastomer material used in downhole equipment caused by RGD with CO₂ gas under different pressures, and carried out quantitative tests to monitor volume change of elastomer samples. It provided an experimental analysis method for service life prediction and safety evaluation under high pressure and high gas content conditions, and guidance of reasonable selection and optimal design of elastomer.

2. Experimental scheme design

2.1 RGD failure feature experiment

Three groups of NBR samples with different thicknesses (Table 1) are hung in reactor filled with CO₂...
gas to 2, 4, 6, 8 MPa, and stabilized for 24 hours. Then pressure is released at the maximum allowable bleeding off rate of the equipment. The appearance feature of the samples before and after the experiment is observed.

Table 1 Geometry of tested NBR samples

| NO. | Geometry (length × width × thickness, mm) | count |
|----|------------------------------------------|-------|
| 1  | 20×20×1.3                                 | 8     |
| 2  | 20×20×2.2                                 | 8     |
| 3  | 20×20×5                                   | 8     |

2.2 Whole process quantitative monitoring experiment

In order to quantitatively monitor the geometrical changes of samples in the whole pressurization, stabilization, decompression and post decompression stages, four reactors with sapphire glass window were selected as well as CO2 gas source and pressure pump.

The geometry of samples in this experiment is 100×1.6×2.0mm. They are placed in reactor, filled with CO2 up to 3, 6, 9, 15MPa respectively, stabilized for 4 hours, and then decompressed to atmosphere pressure with a rate of 2MPa/min. The geometric size change of the samples is monitored and measured during the whole process.

3. Experimental result analysis

3.1 RGD failure feature experiment

When the pressure was 2MPa, no visible expansion and bubbles occurred (Figure 1); When the pressure was 4MPa, visible surface expansion occurred after pressure release, but recovered after a certain period of time without damage (Figure 2); When the pressure is 6MPa, bubbles occurred after pressure release, and cannot recover (Figure 3); When the pressure raised to 7.49MPa (The original set value was 8MPa, but terminated due to pressurization difficulty as reaching supercritical state of CO2), large bubbles occurred (Figure 4), and ruptured through the cross section (Figure 5). The thicker of the sample thickness, the more serious of the failure caused by RGD.

The indoor simulation experiment results show that:

- The volume of elastomer will expand, and irreversible failures such as bubbling and blistering will occur in severe cases during and after RGD.
- The greater of pressure, the easier of RGD failure. The critical pressure point of current NBR elastomer material is about 4MPa for CO2 gas RGD.
- The thicker the more likely the elastomer will fail under RGD.
3.2 Whole process quantitative monitoring experiment

The experimental result is shown in Figure 6, from which it can be found that the sample had certain volume expansion during pressurization and stabilization stage, and achieved equilibrium within 4 hours with a value less than 5%. With the rapid release of pressure, the volume of the sample expanded rapidly. And the larger of the pressure was, the more serious of the volume expansion was. When the pressure was 3 MPa, the maximum volume change was 3%; When the pressure is 6 MPa and 9 MPa, the maximum volume change was 10%; And when the pressure was increased to 15 MPa, the maximum volume change reached to 22%.

![Figure 6 Volume change along with time of the samples under different pressures](image)

The experiment results show that:

- Gas has certain permeability and solubility in elastomer material, and the solubility increases with the increase of pressure, resulting in volume expansion of elastomer. But the value is relatively small at this stage.
- The bubbling and blistering are easy to occur in the stage of decompression and post decompression. With the rapid release of the surrounded gas pressure, the gas dissolved in elastomer expands rapidly due to the decrease of pressure and slow permeating out rate, which results in the rapid increase of rubber volume. And the greater the pressure is, the more obvious the effect is.
- After RGD from a lower pressure, the expanded volume of elastomer can reduce or even restore to its original level within a certain period of time.

The downhole operating pressure of production wells is about 8-10 MPa. Although the present using NBR elastomer material will swell due to CO₂ intrusion, it can still work normally and guarantee sealing effect. However, in the case of tubing string leakage, stopping CO₂ injection and restarting, and too fast POH speed, serious fluctuation of downhole pressure will occur, resulting in bubbling, blistering, and seal failure of elastomer material due to RGD. Corresponding production management regulation should be established on site to strictly limit the pressure fluctuation rate. When sudden pressure relief conditions occur, elastomer sealing components should be verified and replaced timely to ensure safe and normal operation of downhole equipment.

4. RGD failure mechanism analysis

In the micro structure of elastomer, the molecular chains adsorb and link on the surface of carbon black particles, and form the cross-linked grid structure. Under the external pressure and Brownian motion, gas molecules intrude into the inner space of the grid from the surface of elastomer, resulting in threedimensional expansion in the mesh space and increased volume in the macro. For CO₂ gas, especially when the temperature is higher than 31°C and the pressure is greater than 7.1 MPa, it will be in supercritical state. Its properties will change obviously. The density is close to liquid, viscosity is close to gas, and its diffusion coefficient is 100 times that of liquid. Under this condition, CO₂ has strong solubility and mass transfer characteristics, and has strong permeability and solubility for elastomer sealing parts. When the external pressure suddenly decreases, the internal stress and gas concentration
field change rapidly. The gas penetrated into the elastomer will expand instantaneously, thus forming defects such as bubbles and cracks in the rubber.

5. Conclusions
Through the RGD failure feature experiment and whole process quantitative monitoring experiment, the RGD failure appearance, critical pressure point, rule, and mechanism of present using NBR elastomer for downhole packer and PC pump were figured out. The on-site preventive measures were also defined to ensure the safe and efficient development of CO₂ flooding.

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