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Research on Integrity Evaluation Technology for High Pressure Gas Wells in Kuqa Mountain Front

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Abstract: *Safety management of high-pressure gas wells is a prerequisite for ensuring the safe production of high-pressure gas wells. In recent years, with the continuous production of high-pressure gas wells in front of Kuqa Mountain, some gas wells have experienced abnormal annular pressure, which has increased the risk of gas well management. The key points of high-pressure gas well production management are to determine the range of annular pressure control, determine the safety status of abnormal pressure wells, and ensure long-term safety production of high-pressure gas wells. Due to insufficient understanding of these risks in the early stage, effective measures were not taken during the oil testing design and construction process, resulting in multiple high-pressure gas wells experiencing incidents such as tubing string failure and casing deformation during the oil testing process, resulting in operation failure or even scrapping. This article evaluates the annular pressure and control mechanism of high-pressure gas wells based on the current concept of integrity, which cannot meet the complex factors of high-pressure gas wells, and combined with the characteristics of high-pressure gas reservoirs in front of Kuqa Mountain;*

Keywords: *Kuche Mountain Front; High pressure gas wells; Well integrity; evaluate*

1. Introduction

The integrity of a gas well is a key indicator for measuring the structural damage resistance of the wellbore structure and the normal operation of the gas well. During the entire service life of a gas well, if the integrity of the well is damaged, it may lead to accidents such as gas reservoir loss, blowout, and even extremely dangerous consequences. In recent years, the study of gas well integrity has become a hot topic for scholars both domestically and internationally[1]. The Tarim Oilfield and Southwest Oil and Gas Field in China have initially developed relevant technologies for integrity evaluation of deep gas wells, and have explored quantitative evaluation of integrity[2]. After 2000, major oil field companies and related institutions around the world have successively conducted research on gas well integrity evaluation and management technology[3-11]. Most gas wells will experience annular pressure after completing oil testing. If the annular pressure is low, it may affect production and reduce oil recovery; If severe, it may cause damage to the integrity of the well and even lead to natural gas leakage, causing serious consequences[12-15]. So far, there is no clear and accurate concept of gas well integrity at home and abroad. The concept of gas well integrity was proposed by API-RPI90, NORSOKD-010, and Halliburton, all of which indicate that gas well integrity effectively controls the safe operating state of formation fluids[16]. If there is uncontrolled fluid flow (interlayer flow or flow to the surface) in a local formation, it is determined that the integrity of the gas well has failed. During the production process, when uncontrolled fluid flow occurs in the local formation and exceeds the acceptable range, the integrity of the gas well is considered to have failed, and measures such as shutting in the well and stopping operations are taken.

For high-pressure gas wells, the determination of integrity failure due to factors such as high pressure is completely different from traditional wellbore methods. At present, the existing integrity concept cannot meet the requirements of wellbore integrity management and needs further development and improvement. Therefore, the core content of integrity management for high-pressure gas wells is to establish integrity evaluation indicators. However, the evaluation indicators for these types of wells are mostly in the drilling and completion stages, and there is a lack of corresponding evaluation systems to guide integrity management in the production process[17].

This article evaluates the annular pressure and control mechanism of high-pressure gas wells based on the current concept of integrity, which cannot meet the complex factors of high-pressure gas wells, and combined with the characteristics of high-pressure gas reservoirs in front of Kuqa Mountain;

2. Current status of integrity of high-pressure gas wells in front of Kuqa Mountain

The international definition of ultra-high pressure gas wells generally refers to gas wells with a bottomhole pressure greater than 103MPa and a depth exceeding 6000m, as shown in Table 1. There are a large number of ultra-high pressure gas reservoirs in front of Kuche Mountain in Tarim Oilfield. The widespread existence of ultra-high pressure gas reservoirs has attracted high attention from domestic and foreign geologists and reservoir engineering experts, and the development prospects are very optimistic.

Table 1: Regulations for International Ultra High Pressure Wellheads

temperature	pressure	Well depth
High temperature: bottom hole temperature>150℃ Ultra high temperature: bottom hole temperature>175℃	High pressure: bottomhole pressure>70MPa Ultra high pressure: bottomhole pressure>103MPa	Deep well: well depth>4500m Ultra deep well: well depth>6000m

In April 2023, according to the statistics on the integrity failure of high-pressure gas wells in front of Kuqa Mountain, there were a total of 283 high-temperature and high-pressure gas wells, and 59 wells with abnormal annular pressure, accounting for 20.85% of the total number of wells; According to the principle of well integrity classification, there are 23 orange wells, accounting for 8.13%, and 36 yellow wells, accounting for 12.72%, as shown in Table 2.

Table 2: Principles and Control Measures for Well Integrity Classification

	graded principles	Control measures	Number of wells
Red	The first barrier fails, the second barrier is damaged (or fails), and the risk assessment confirms it as high-risk; Or it may have leaked to the ground.	After the determination of the red well, it must be treated immediately. The business management department should immediately organize the preparation of a governance plan, and the production unit should immediately take emergency plans, implement risk reduction measures, and prevent and control risks; Organize the implementation of governance plans.	0
Orange	The first barrier is damaged (or fails), and the second barrier is intact; Or if the first barrier is damaged (or fails), while the second barrier is damaged, it is confirmed as medium or low risk after risk assessment.	Firstly, develop an emergency plan to monitor production or take risk reduction measures based on the situation, reduce production and minimize pressure relief or replenishment of the annulus as much as possible; Closely track production dynamics, promptly analyze and evaluate any issues found, and take corresponding measures.	23 (8.13%)
Yellow	The first barrier is intact, while the second barrier is damaged. After risk assessment, it is confirmed as low risk.	Take maintenance or risk reduction measures to maintain stable production and closely monitor changes in pressure in each annulus; Minimize the use of pressure relief or replenishment measures on the annulus as much as possible.	36 (12.72%)
Green	The first and second barriers are in good condition.	Normal monitoring and maintenance.	224 (79.15%)

Among them, there are 45 wells with abnormal pressure in the A annulus, accounting for 76.27% of the total number of wells with abnormal pressure in the annulus. They are mainly divided into: 38 wells with tubing string failure/leakage, 4 wells with unsealed packers, 2 wells with downhole safety valve failures, and 1 well with cement ring bell mouth leakage. There are 10 wells with abnormal pressure in the B annulus, accounting for 16.94% of the total number of wells with abnormal pressure in the annulus. They are mainly divided into: production casing failure, and 6 wells with abnormal pressure in the A annulus flowing into the B annulus; The unqualified cementing quality of the salt layer caused 4 wells to leak. There are 8 wells with abnormal pressure in the C annulus, accounting for 13.55% of the total number of wells with abnormal pressure in the annulus. They are mainly divided into: production casing failure, technical casing leakage, A annulus pressure channeling to B annulus, and B annulus pressure channeling to C annulus; The unqualified quality of salt cementing caused 5 high-pressure

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fluids to flow up with pressure. The main cause of abnormal annular pressure is the failure of the tubing string, accounting for 60.32%, followed by the failure of the cementing cement sheath, accounting for 15.87%, as shown in Table 3 and Figure 1.

Table 3: Failure of Annular Abnormal Pressure Well Barrier

Annular pressure type	Failure barrier level	Well barrier issues	Well number
Abnormal pressure in annulus A (45 wells)	Primary well barrier failure	Underground safety valve failure	2
		Tubing	38
		Packer loss of sealing	4
	Secondary well barrier failure	Cement ring failure (tail pipe bell mouth)	1
Abnormal pressure in B annulus (10 wells)	Secondary well barrier failure	Cement sheath failure (unqualified cementing)	4
		Production casing failure	6
Abnormal pressure in the C annulus (8 wells)	Secondary well barrier failure	Cement sheath failure (unqualified cementing)	5
		Technical casing failure	3

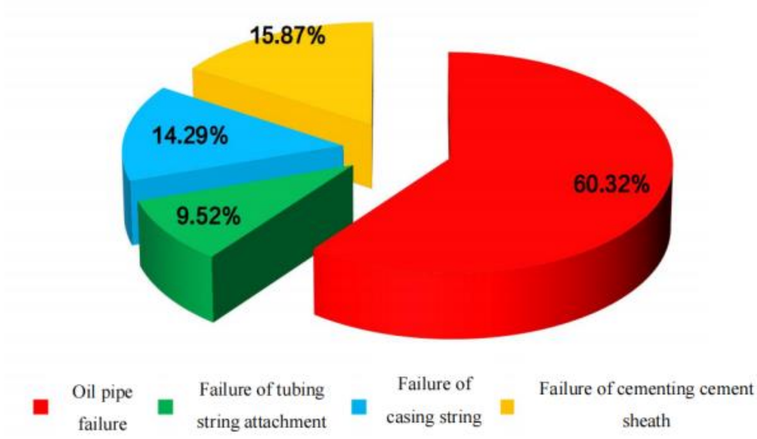

Figure 1: Failure of Well Barrier

3. Analysis of factors affecting the integrity of high-pressure gas wells

As an important oil well barrier device, casing is an important guarantee to prevent fluid leakage in the wellbore. According to current survey data, the drill pipe in deep wells is relatively long, and the reciprocating motion and rotation of the drill pipe in the casing during the drilling process are eccentric. With the extension of drilling time, the radial and axial friction between the drill pipe and the casing will cause severe wear on the outer wall of the drill pipe and the inner wall of the casing, mainly occurring at the joint of the drill pipe. Due to the relative motion of the drill pipe, its wear is usually uniform, while the casing only undergoes localized uneven wear. This type of casing wear directly affects the integrity of the high-pressure gas well wellbore.

The cementing cement sheath is mainly used to support and suspend the casing, protect the wellbore, block formation fluids, and provide a certain alkaline environment to prevent corrosive fluids from corroding the casing. Therefore, it is necessary to evaluate the performance and quality of the cementing cement sheath, laying the foundation for the integrity evaluation of this type of gas well.

4. Analysis of Abnormal Integrity Phenomenon of Kuqa Mountain Front Gas Well

Through the evaluation of well integrity risk indicators for wells that have been put into operation in front of Kuqa Mountain, the main problems faced by the integrity of the wells in front of Kuqa Mountain are the difficulty in improving the quality of well construction, severe abnormal pressure in the annulus, and high difficulty in safety control, mainly reflected in the following aspects:

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(1) Casing string

The development of a composite salt gypsum layer in the formation requires higher casing strength; At the same time, high-pressure gas also requires higher sealing of the casing thread.

(2) Wellhead

The wellhead of the high-pressure gas well in front of Kuche Mountain is high-temperature and high-pressure, and the rubber parts are prone to aging.

(3) Cement sheath

Due to high-pressure gas/water channeling, there is pressure in the annulus after cementing; Narrow density window, narrow annular space gap, and low centering of non coupling sleeve; High displacement displacement displacement, pressure stability and channeling prevention, as well as long-term sealing at high temperatures and pressures, pose higher requirements for cementing cement rings.

(4) Tubing string

The Cl^- content exceeds 80000mg/L, the CO2 partial pressure exceeds 1MPa, and the alternating corrosion environment of fresh acid, residual acid, condensate water, and formation water requires high corrosion resistance of the tubing string material; At the same time, as the depth of the well increases, the performance requirements for downhole tools become higher.

5. Response Measures for Integrity of Kuqa Mountain Front Gas Well

5.1 Strengthen wellbore quality control to ensure "well construction" during the well construction phase

In response to the problems of narrow annular space gap and poor cementing quality in ultra deep casing, a high-performance small coupling gas sealing buckle has been developed and designed by optimizing the joint thread and sealing surface structure, as shown in Figure 2. It can be used in conjunction with a centralizer and has been applied in 5 wells, improving cementing quality by 20%.

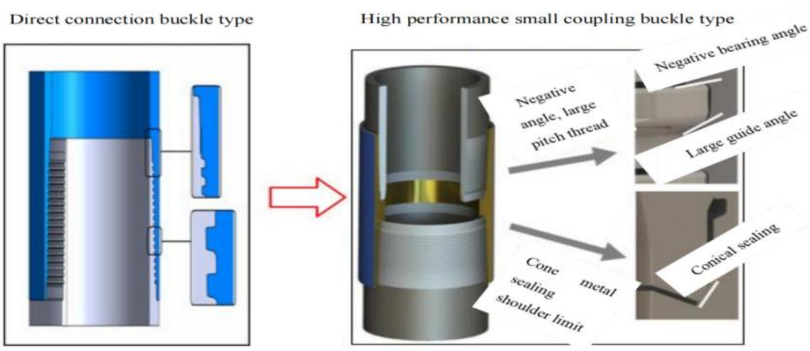

Figure 2: High performance small coupling gas sealing buckle diagram

Table 4: Measures and Indicators for Improving the Strength of Three High Squeezing Resistance Specification Sleeves

Improvement measures	8 1/8″*19.05	7 5/8″*12.70	11 3/4″*26.59
Thickening design	upset	upset	external upset
Steel grade improvement	140KSI↑155KSI	/	140KSI↑155KSI
joint structure	Direct connection type optimized for small coupling	/	/
Resistance to external compression	185MPa	106MPa	182MPa

In response to the problem of deformation caused by the collapse of the salt paste layer casing, three types of high resistance casing were developed and designed through measures such as improving the material steel grade, external thickening design, and optimizing the joint structure. As shown in Table 4, the maximum resistance to external collapse reached 185MPa, effectively addressing the high risk of salt paste layer collapse.

In view of the fracture problem of high grade steel (155KSI) casing in Kuqa Shanqian high-pressure gas well, through indoor failure analysis, it is verified that the mismatch between high grade steel (155KSI) and phosphate completion fluid is the main cause of stress corrosion cracking of casing, and the failure mechanism is stress corrosion cracking. Through the analysis of fracture toughness data and field load of high grade steel, as shown in Figure 3, combined with the method of failure assessment chart. A fracture sensitivity evaluation model for high-grade steel casing has been established to provide technical guidance for its safety under actual service conditions on site.

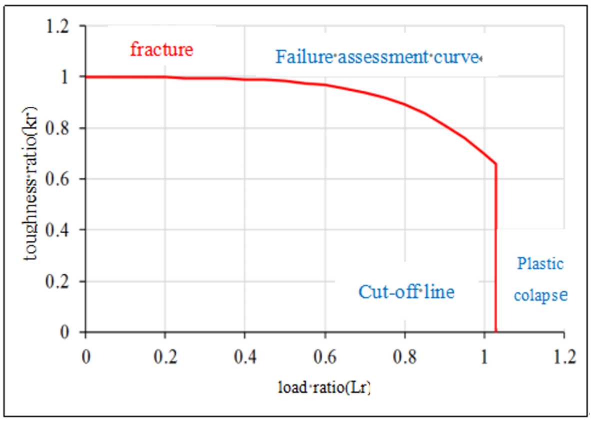

Figure 3: Sensitivity evaluation of 155KSI steel grade casing fracture

Breaking through the traditional concept of gradually decreasing barrier strength, a two-stage barrier design model with equal strength in the wellbore has been established. A 140MPa production casing and casing head, as shown in Figure 4, have been developed, which are combined with equal strength tubing strings and Christmas trees to strengthen the wellbore barrier and achieve "dual safety" for wellbore pressure bearing.

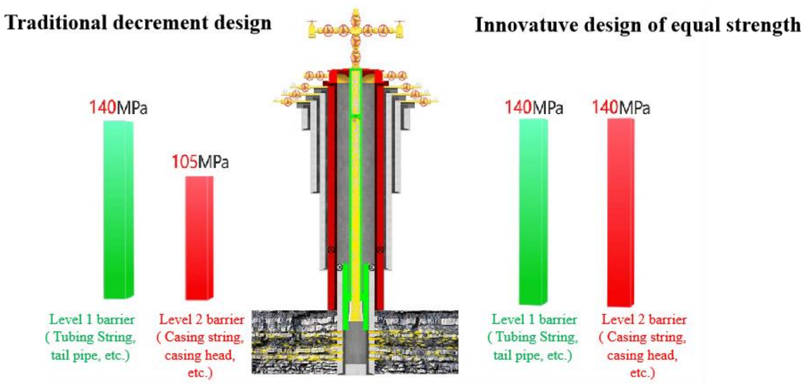

Figure 4: Schematic diagram of equal strength well barrier design

5.2 Strengthen fine pressure control to ensure "well management" during the production stage

We will tackle key issues in terms of annulus pressure control, abnormal well management, standardization of well integrity, and informatization, and refine well integrity production control to ensure continuous and stable production of normal wells and safe and effective control of abnormal wells.

Innovative simulation methods for water hammer effects in "three high" gas wells have been developed, clarifying the main influencing factors of water hammer effects in different operating well conditions. Based on the comparison and correction of experimental data, a simulation model for the water hammer effect in ultra deep wells was established. Water hammer effect analysis was conducted under pump shutdown, sand blockage, and well shut-in conditions, as shown in Figure 5, forming a set of water hammer effect simulation methods. This provides a theoretical basis for optimizing the pipe

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structure and determining the boundary of on-site operations, clarifies the main influencing factors of water hammer effect in different well conditions, and proposes mitigation measures for water hammer effect.

The main influencing factors under sand blockage working conditions are fracturing displacement, pump stop reaction time, and total pump stop time. Shortening the pump stop reaction time after sand blockage can alleviate the risk of water hammer caused by sand blockage,as shown in Figure 5a.

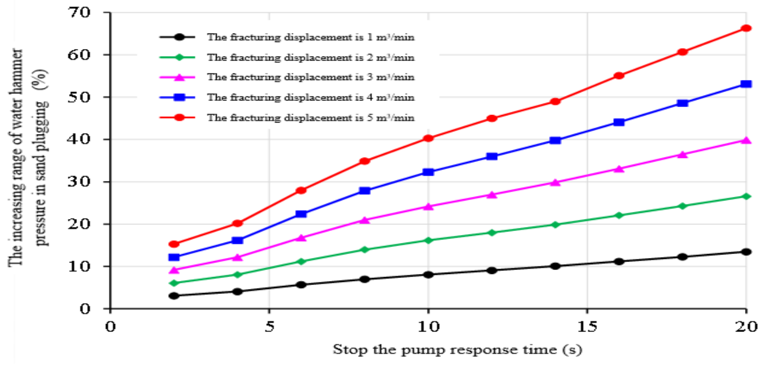

Figure 5a: Shorten the reaction time of pump shutdown after sand blockage

The main influencing factors under pump shutdown conditions are fracturing displacement, time for complete pump shutdown, outer diameter of the pipe string, etc. Reducing the fracturing displacement before pump shutdown and extending the time for complete pump shutdown can alleviate the risk of water hammer caused by pump shutdown,as shown in Figure 5b.

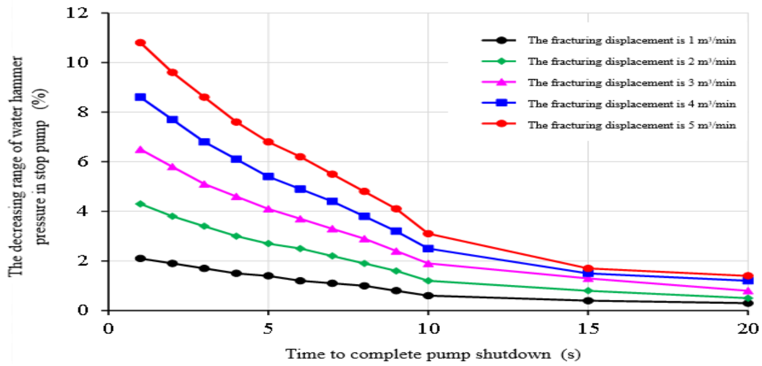

Figure 5b: Fracturing displacement before pump shutdown and extending the time for complete pump shutdown

The main influencing factors under shut-in conditions are shut-in time, production rate, initial pressure, liquid phase content, etc. A pressure controlled slow shut-in can be adopted to alleviate the water hammer zone during shut-in,as shown in Figure 5c.

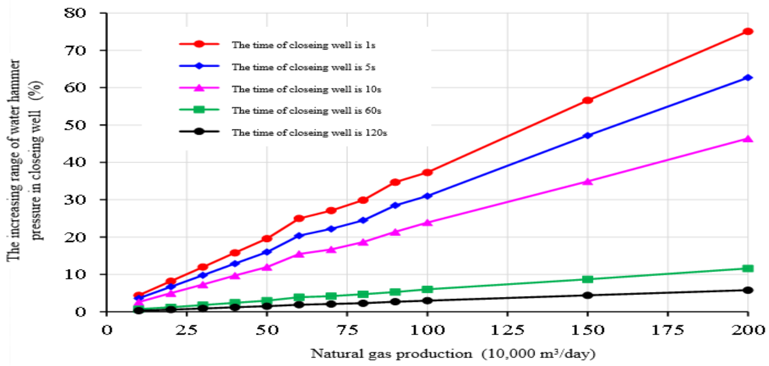

Figure 5c: Pressure type slow shut-in

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5.3 Strengthen graded and classified disposal to ensure "well governance" during the governance stage

We have established principles and plans for the classification and management of high-pressure gas wells, which can be repaired without repair, minor repairs without major repairs, and no more than once; The integrity of the pipe string is good, and the wellbore is severely blocked. Timely acidizing and unblocking should be carried out; The integrity of the tubing string is damaged, the wellbore is severely blocked, sand or scale is blocked, and the tubing string should be unblocked in a timely manner with continuous tubing; If the integrity of the well fails or there are other safety hazards (red well), immediately overhaul and replace the pipe string.

The wellbore is blocked, and the wellbore is unblocked to alleviate the integrity problem of the well. Six types of unblocking processes are provided (as shown in Figure 6) to achieve safe and efficient unblocking, restore gas well production capacity, and ensure stable production of the gas well. This avoids damage to the tubing caused by severe oil pressure fluctuations, and alleviates the failure of the tubing string. From 2020 to 2022, a total of 49 wells (37 high-pressure gas wells and 12 drainage wells) were used for non acidic unblocking liquid systems, with an effective rate of 95.6%. After unblocking, the average single well production capacity of gas wells increased from 48 × 104m3/d increased to 163 × 104m3/d, increased by 2.4 times.

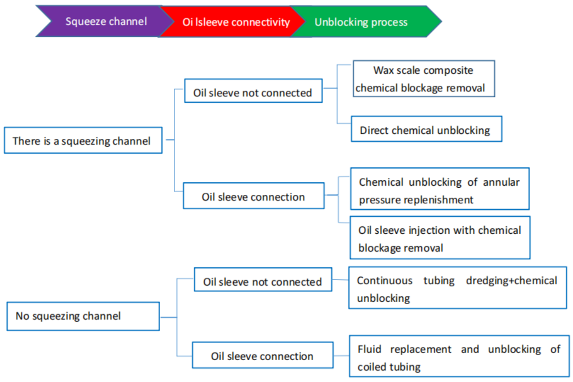

Figure 6: Six types of wellbore unblocking processes

5.4 Strengthen the management of blocking barriers to ensure that the well is "sealed" during the disposal phase

For gas wells with significant safety hazards such as lost production capacity and irreparable well barriers, a permanent abandonment and sealing specification has been established (as shown in Figure 7), which specifies the specific sealing requirements for abandoned wells, strengthens the testing requirements for sealing barriers, and ensures that abandoned wells do not leak. Since the implementation of oilfield well sealing standards, a total of 70 well closures have been implemented, with a success rate of 100%.

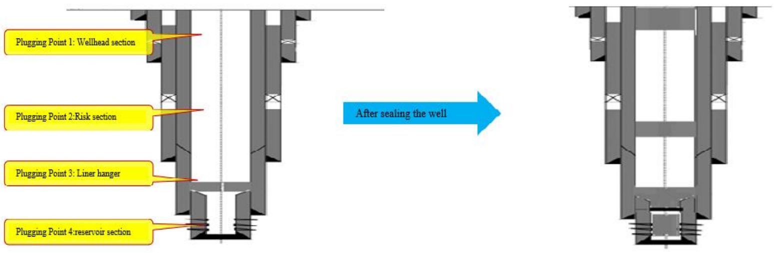

Figure 7: Schematic diagram of wellbore structure comparison before and after well sealing

6. Application Results of Integrity of Kuqa Mountain Front Gas Well

(1) The quality of well construction continues to improve. In the face of increasingly harsh

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engineering geological conditions, the integrity and integrity rate of newly built wells remains 100% within one year of production, effectively reducing the increment of abnormal annular pressure, as shown in Figure 8.

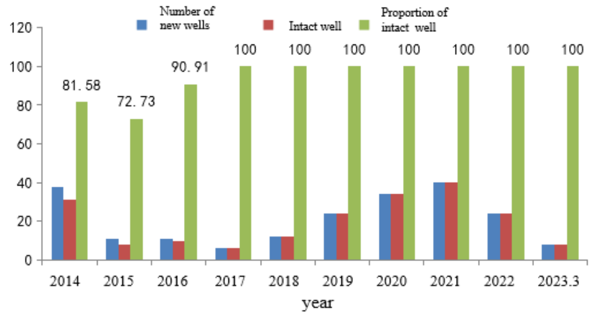

Figure 8: Well integrity rate within one year of production in front of Kuche Mountain

(2) The production control is stable and controlled, and the safety control is 30 billion cubic meters of high-temperature and high-pressure gas fields. The proportion of abnormal pressure wells has decreased year by year to 20.85%, and the proportion of orange wells has decreased year by year to 8.13%, as shown in Figure 9.

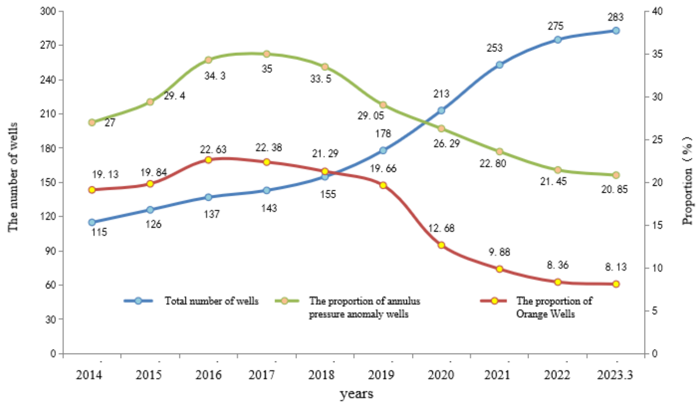

Figure 9: Proportion of Abnormal Pressure Wells in Kuche Mountain Front

7. Conclusion

(1) In response to the integrity issue of gas wells in front of Kuqa Mountain, corresponding technical policies have been formulated, and the current status, influencing factors, and abnormal situations of gas well integrity in front of Kuqa Mountain have been analyzed to ensure safe production of gas wells.

(2) Corresponding measures have been proposed to address the current situation of integrity in the Kuqa Mountain front gas well from four aspects: well construction, well management, well treatment, and well sealing, laying a solid foundation for on-site application.

(3) The integrity and integrity rate of the newly built well in front of Kuche Mountain remains 100% within one year of production, effectively reducing the increment of abnormal pressure in the annulus, and the proportion of abnormal pressure wells is decreasing year by year.

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