Classification and Application of Tight Gas Wells Based on Cluster Analysis

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Abstract. The tight gas field is greatly affected by pressure in the development process. Due to the different production time and formation pressure of each well in the gas field, the production characteristics of the gas well are obviously different. After the gas well sees water, it is impossible to formulate production measures efficiently and accurately. Therefore, by analyzing the production performance characteristics of gas wells, this paper carries out the classification research of tight gas wells, and formulates the corresponding production measures according to the classification results. Taking gas well energy and liquid production intensity as the reference standard of gas well classification, the dynamic parameter indexes characterizing gas well energy and liquid production intensity are established. Gas wells with different production characteristics are divided into six categories by clustering algorithm: high energy-low liquid, high energy-high liquid, medium energy-low liquid, medium energy high-liquid, low energy-low liquid, low energy-high liquid. Then the classification method of tight gas well is formed. In this paper, 50 wells in Linxing block are selected as the research object. The research results show that most of the wells in Linxing block are located in area V, belonging to low energy and low liquid wells. It is recommended to implement intermittent production. The classification based on gas well energy and liquid production intensity are of guiding significance for the formulation of production measures in the Linxing block.

Keywords: Gas well classification; Gas well energy; Liquid production intensity; Cluster analysis; Drainage Gas Production.

1. Introduction
Many scholars have done relevant research on gas well classification: Luo Wanjing et al [1] divided gas wells into five categories by establishing two evaluation indexes of daily production and decline rate. Yang jiaosheng et al [2] studied the production characteristics of 20 experimental wells in Fanzhuang block, and divided the gas wells into three categories. Li Qiang et al [3] divided low production gas wells into continuous production wells and intermittent production wells with daily gas production, pressure drop rate, production pressure difference and gas production per unit pressure drop as evaluation indexes. Li Tiantai et al [4] determined the evaluation indexes of horizontal well classification through a lot of research and analysis. Through cluster analysis, the gas wells were divided into low production and high-speed decline wells, middle production and low-speed decline wells. Feng qianghan et al [5] took gas production and casing pressure as classification indexes, and considered wellbore technology, established multi-dimensional matrix template diagram of gas well classification management, and subdivided gas wells into 48 categories. Gao Wangbin et al [6] conducted principal component and cluster...
analysis on the factors affecting bubble drainage, divided bubble drainage wells into five categories, and recommended corresponding bubble drainage agents according to the characteristics of each category of wells. Hou Chenhong et al[7] considered the physical properties of the reservoir and the production of gas wells, divided the gas wells into four categories, analyzed the characteristics of each type of well, and formulated the corresponding production system and drainage measures based on the results of the gas well classification. Jia Yanran et al[8] considered the reservoir physical parameters and gas well production performance data, adopted the orthogonal matrix method, obtained the gas well classification results of dynamic and static combination, and defined the formulation of production measures. Based on the previous research results, this paper summarizes the dynamic classification indexes of gas well energy and liquid production intensity, analyzes the production characteristics of gas wells, and establishes a set of gas well classification standards based on gas well energy and liquid production intensity, the reasonable classification of gas wells is realized. Taking Linxing block as the research object, the reliability of the classification results is verified, and the corresponding measures are put forward.

2. Analysis of Production Characteristics of Tight Gas Wells

Linxing block, located in the east of Ordos Basin, is an important natural gas exploration and Development Zone in China, with large dense sandstone gas reservoir. The average gas production of Linxing block is $6.5 \times 10^4 \text{m}^3/\text{d}$, and the daily average output of a single well is $0.79 \times 10^4 \text{m}^3$, the maximum gas-liquid ratio is $0.68 \text{m}^3/10^4 \text{m}^3$, the average gas-liquid ratio is $0.14 \text{m}^3/10^4 \text{m}^3$, the average casing pressure is $5.05 \text{MPa}$, and the average oil pressure is $4.86 \text{MPa}$. 50% of the wells in the block enter the low pressure and production stage[9-11]. Figure 1 shows the gas production and liquid production curve of well W1 during production. The curve shows that the average gas production of gas well is $8000 \text{m}^3$, and the gas well starts to produce liquid after a period of production. Figure 2 shows the oil and casing pressure change curve of well W1 during production. The curve that the oil and casing pressure change trend of well W1 is basically the same during production. Figure 3 shows the gas production and liquid production change curve of well W3 during production. The curve shows that the water production of well W2 is large, with the average water yield of $1 \text{m}^3$, the gas production of gas well drops rapidly, and the gas production is below $5000 \text{m}^3$. After that, there is no liquid production curve in the curve, which may be due to the low production of gas well, so it is impossible to discharge liquid. The drainage measures should be taken to prevent the gas well from being crushed. Figure 4 shows the oil and casing pressure change curve of well W2. The curve shows that the difference between oil and casing pressure is large. It is further verified that there is bottom hole liquid loading in well W2, and some drainage measures are needed.
Through the analysis of the production characteristics of W1 and W2 wells, we can only find some existing problems, and can not deeply understand the production characteristics of gas wells, so reasonable production measures can not be made. Therefore, it is necessary to establish gas well evaluation index, classify gas wells, summarize the production characteristics of different types of gas wells, and provide basis for the next step of development plan adjustment.

3. Gas Well Classification Index and Evaluation Method

The purpose of gas well classification is to study the production characteristics of different types of gas wells, so as to formulate corresponding production measures for different types of gas wells. Before gas well classification, it is necessary to establish the relevant indexes of gas well evaluation, which are easy to obtain and can characterize the production characteristics of gas wells. After obtaining the evaluation indexes, the evaluation indexes are analyzed by clustering algorithm, and then the classification results of gas wells are determined.

3.1. Evaluation Index Selection

In this paper, combined with the actual production in Linxing block, the factors affecting the production effect of water producing gas wells are analyzed, and the gas wells are classified and evaluated from two aspects of gas well energy and liquid production intensity.

The formation energy and liquid production intensity of gas well can be reflected by dynamic production data. In the dynamic data, gas production, dynamic differential pressure, residual pressure, water production and standard deviation of water gas ratio are selected as the evaluation indexes of gas well classification, in which gas production, falling time of well opening pressure and residual pressure are used as the evaluation indexes of gas well energy, and water production and standard deviation of water gas ratio are used as the evaluation indexes of liquid production intensity. The production status of gas well reflected by these indexes is shown in Table 1.

| Index | The significance of indicators | Gas well status characterized |
|-------|--------------------------------|-----------------------------|
| Gas production | The average gas production in the current stage, which represents the production, reflects the gas production capacity, and reflects the adjustable range of gas well production | The larger the gas production is, the more sufficient the energy is. |
| Time of well opening pressure falling back | The time required for oil pressure to fall to the level before shut in after opening indicates that the formation energy supplement during shut-in can support the stable production time under certain gas production level. The strength and weakness of the formation supplement ability | The longer the opening pressure falls, the faster the formation energy replenishment |
| Residual pressure | The difference between the oil pressure level of the gas well and the discharge pressure indicates the pressure maintaining level of the gas well and reflects the adjustable range of the oil pressure | The larger the residual pressure, the more sufficient the energy, and the smaller the influence of the back pressure produced by the surface pipeline |
| Water yield | The average water production in the current stage is the water production and reflects the water production level | The greater the water production, the greater the water production capacity |
| Standard deviation of water gas ratio | The standard deviation of the initial water air ratio and the current water air ratio relative to the average water air ratio indicates the change of water production and reflects the change trend of water production | The larger the standard deviation of water gas ratio, the greater the water supply capacity of the formation |
3.2. Establishment of Gas Well Classification Model
After determining the gas well classification evaluation index, the gas well classification model is established, and the corresponding production measures are designed according to the production characteristics after classification.

(1) Select the performance index which is easy to obtain and can represent the production characteristics of gas well.

(2) The dynamic indexes are divided into two groups: gas well energy and liquid production intensity. The indexes of gas well energy include gas production, opening pressure falling time and residual pressure, and the indexes of liquid production intensity include water production and standard deviation of water gas ratio.

(3) The dynamic index data were normalized.

(4) Using k-means cluster analysis, single well types are divided according to gas well energy and liquid production intensity data.

(5) According to the classification, the production characteristics of gas wells are analyzed, and the corresponding optimization measures are formulated.

3.3. Evaluation Index Data Processing
Due to the different units and orders of magnitude of the production index data collected and calculated in Linxing block, large orders of magnitude data will appear when clustering the data, which makes the small orders of magnitude data invalid and brings difficulties to the clustering algorithm.

In order to solve this problem, we need to preprocess the data. In the example, the type normalization method is used to deal with the parameters of gas well classification and evaluation index.

3.4. K-means Clustering Analysis
By collecting the actual production data of gas wells, the dynamic evaluation index parameters of each well are set as a group of data points, and the clustering algorithm is used to classify the evaluation index data points. The gas wells in the same group have similar characteristics, while the gas wells in different groups have different characteristics. This method can divide the gas wells with different production characteristics into different groups, so as to realize the classification of gas wells.

The data processing process of gas well energy index based on K-means algorithm is as follows:

(1) Assuming that the gas wells are divided into n categories according to the energy evaluation index parameters, n initial cluster centers are selected:

\[ M_1(0), M_2(0), \ldots, M_n(0) \]

Where 0 in parentheses represents the number of iterations.

(2) According to the principle of minimum distance, the data points composed of gas well energy evaluation index parameters are assigned to one of N clustering centers:

\[ \min \{ \| X - M_i(0) \|, i = 1, 2, \ldots, n \} = \| X - M_i(0) \| = S_i \]

Where x is the data point vector composed of gas well energy evaluation index parameters, and Si is the minimum distance from a well to the cluster center of class I. at this time, the well is divided into class i wells.

(3) After the gas wells are preliminarily classified in step (2), the data center of each kind of wells is calculated as the new clustering center of this kind of wells:

\[ M_i(1) = \frac{1}{N_i} \sum_{x \in S_i} X, \quad i = 1, 2, \ldots, n \]

Where Ni is the number of class i wells and Si is the data point set of class i wells.

(4) If \( M_i(1) \neq M_i(0), \quad i = 1, 2, \ldots, K \), then the data points are reclassified and the iterative calculation is repeated until \( M_i(K+1) = M_i(K), \quad i = 1, 2, \ldots, K \), then the algorithm converges and the iteration ends.

Through the above steps, gas wells can be divided into different types according to the energy indexes. By comparing and analyzing the index parameters of different types, it is determined that a certain type
of well belongs to high energy well or low energy well. In the same way, this method can get the result of classification according to the liquid production intensity.

4. Case Study
Taking Linxing block as an example, through the collection of actual production data, taking gas production, dynamic pressure difference, residual pressure, water production and standard deviation of water gas ratio as gas well classification evaluation indexes, the clustering algorithm is applied to classify 50 gas wells in Linxing block.

According to the field data and calculation results, the classification evaluation index parameters of 50 wells in Linxing block are obtained, as shown in Table 2.

| Well number | Gas production (m³) | Time of well opening pressure fallback (day) | Residual pressure (MPa) | Water yield (m³) | Standard deviation of water gas ratio |
|-------------|---------------------|---------------------------------------------|-------------------------|-----------------|-------------------------------------|
| W1          | 5620                | 28                                          | 1.5                     | 5.6             | 0.22                                |
| W2          | 13795               | 73                                          | 2.6                     | 5.2             | 1.79                                |
| W3          | 8891                | 50                                          | 3.4                     | 2.5             | 0.26                                |
| W4          | 5338                | 30                                          | 1.5                     | 6.8             | 2.57                                |
| W47         | 10200               | 77                                          | 2.47                    | 2.5             | 0.91                                |
| W48         | 9007                | 53                                          | 1.35                    | 3.8             | 1.12                                |
| W49         | 9237                | 33                                          | 1.35                    | 8.7             | 1.8                                 |
| W50         | 8628                | 47                                          | 1.52                    | 6.1             | 1.01                                |

Clustering algorithm is used to classify the normalized data. The results of K-means clustering analysis on three indexes of gas well energy are shown in Figure 5. The gas wells are divided into three categories according to the energy, and the asterisk represents the cluster center.

The low residual pressure, low gas production and short falling time of opening pressure of gas wells in area 1 are the manifestations of insufficient energy. Therefore, the gas wells in area 1 are low energy wells. The residual pressure in the three zones is sufficient, the gas well production is high, and the opening pressure drops for a long time, indicating that the gas well energy is sufficient, and the gas wells in the three zones are high energy wells. The residual pressure, gas production and opening pressure drop time in zone 2 are between zone 1 and zone 2, and the energy is in the medium level.

The results of K-means clustering analysis on two indexes of liquid production intensity are shown in Figure 6. The asterisk in the graph represents the cluster center.

The gas wells in the first area have low water production and the standard deviation of water gas ratio is small, which indicates that the liquid production intensity of the gas wells is small, that is, the gas wells in the first area indicate the wells with low liquid production intensity. The standard deviation of water gas ratio is larger than that of the first area, which means that the well in the second area has high liquid production intensity.

Based on cluster analysis of production performance indexes of energy and liquid production intensity, gas wells can be divided into six categories: high energy high production liquid, high energy low production liquid, low energy high production liquid, low energy low production liquid, medium energy high production liquid, and medium energy low production liquid.
production liquid, medium energy high production liquid, medium energy low production liquid, low energy high production liquid and low energy low production liquid. The classification of gas well production characteristics is shown in Table 3. The classification results of 50 gas wells in Linxing block are shown in Table 4.

**Table 3. Classification of gas wells.**

| Liquid production intensity | High energy | Medium energy | Low energy |
|----------------------------|-------------|---------------|------------|
| High yield liquid          | I           | II            | III        |
| Low yield liquid           | IV          | V             | VI         |

**Table 4. Classification results of gas wells in Linxing block.**

| Well number | gas production /m³ | Time of well opening fallback /d | Residual pressure /MPa | Water yield /m³ | Standard deviation of water air ratio | Type |
|-------------|---------------------|----------------------------------|------------------------|-----------------|--------------------------------------|------|
| W1          | 5620                | 28                               | 1.5                    | 5.6             | 0.22                                 | VI   |
| W2          | 13795               | 73                               | 2.6                    | 5.2             | 1.79                                 | I    |
| W3          | 8891                | 50                               | 3.4                    | 2.5             | 0.26                                 | V    |
| W4          | 5338                | 30                               | 1.5                    | 6.8             | 2.57                                 | III  |
| W47         | 10200               | 77                               | 2.47                   | 2.5             | 0.91                                 | I    |
| W48         | 9007                | 53                               | 1.35                   | 3.8             | 1.12                                 | V    |
| W49         | 9237                | 33                               | 1.35                   | 8.7             | 1.8                                  | II   |
| W50         | 8628                | 47                               | 1.52                   | 6.1             | 1.01                                 | II   |

(1) Type I gas well means that the gas well has high energy and high water production, and the optimizing tubing can be selected to assist the gas well to lift a large amount of water to the surface, so as to ensure that the gas well will not have the problem of liquid accumulation;
(2) Type II gas well means that the energy is at medium level and the liquid production is high, so plunger gas lift can be used to ensure the normal operation of gas well;
(3) Type III gas well means that the energy of gas well is low, but the water production is high. This kind of well will inevitably produce bottom hole effusion. If no strong drainage measures are taken, The wellbore will accumulate fluid. Continuous gas lift, electric submersible pump and other strong drainage measures are recommended to ensure the normal production of gas well;
(4) Type IV gas well means that the gas well has high energy and low water production. This type of well basically does not produce bottom hole liquid loading. It is an excellent well to ensure the production in the gas field. It does not need to take any production measures, but dynamic parameters should be monitored;
(5) Type V gas well means that the energy is at medium level and the liquid production is small, so the foam drainage gas production can be used to ensure that the gas well does not produce liquid;
(6) Type VI gas well means that the energy and liquid production of gas well are relatively low, and the conventional production technology can not meet the production requirements. According to this feature, intermittent production can be selected.

**Table 5. Corresponding measures for different types of gas wells.**

| Liquid production intensity | High energy/Recommended measures | Low yield liquid/Recommended measures |
|----------------------------|----------------------------------|--------------------------------------|
| High energy                | Type I Optimizing tubing         | Type IV No measures need to be taken |
| Medium energy              | Type II Plunger gas lift         | Type V Foam drainage gas production  |
| Low energy                 | Type III Continuous gas lift and ESP | Type VI Intermittent production |
To sum up, the recommended process measures for different types of gas wells are shown in Table 5. According to the classification results of gas wells in Linxing block, 60% of the gas wells in the block are characterized by low energy and low liquid production. It is necessary to focus on the development of production measures for this type of gas wells, so as to ensure the stable and safe production of gas wells in the block. For this type of wells, intermittent production is preferred.

5. Conclusion

(1) A set of gas well classification and evaluation methods is established, and gas well classification evaluation indexes are determined. All these indexes are easy to obtain, which can provide reference for reasonable and effective gas well management Effective classification provides the data base.

(2) The production performance index data are analyzed by using clustering algorithm. Gas wells are divided into six categories according to energy and liquid production intensity. The classification results are obvious. Different types of wells have great differences in production characteristics. And the complexity and subjectivity of manual classification are solved.

(3) Based on the classification, this paper studies the production data and summarizes the production characteristics of each type of gas wells, and puts forward corresponding production measures, which has reference significance for guiding the development of Linxing block.

References

[1] Luo Wanjing, Wang Xiaodong, Fan Xinwen. Study on classification and evaluation method of gas wells in Sebei No.1 gas field [J]. Xinjiang oil and natural gas, 2007 (04): 25-27+104

[2] Yang Jiaosheng, Li Anqi. Development performance analysis and classification evaluation of coalbed methane wells in Fanzhuang block [J]. Natural gas industry, 2008 (03): 96-98 + 146-147

[3] Li Qiang, Zhao Baoli, Han Qiaorong. Production performance analysis and management method of low production and low efficiency wells in Zizhou Mizhi gas field [J]. Acta petrologica Sinica, 2009,31 (03): 318-320

[4] Li Tiantai, Mou Maoyuan, Zhang Xin, Li Wenpeng, ye Xiaochuang, Li Chunxia. Horizontal well classification and evaluation method based on dynamic data: a case study of Su 14 block [J]. Journal of Xi'an University of Petroleum (NATURAL SCIENCE EDITION), 2015,30 (05): 31-36 + 7

[5] Feng Qianghan, Li Jianqi, Wei Meiji, Yang Shengguo, Cao Caiyun. Differential management strategies for low production and low efficiency wells in Sulige gas field [J]. Natural gas industry, 2016,36 (11): 28-36

[6] GAO Wangbin, DANG Xiaofeng, LI Bopeng, et al. Classification of foam drainage gas production wells based on principal component analysis and cluster analysis [J]. Journal of Xi'an Shiyou University (Natural Science Edition), 2018,33 (1) :6874.

[7] Hou Chenhong, Shi Juntai, Liu Cheng, et al. Classification and evaluation method of CBM wells in block M [J]. Natural Gas Industry.

[8] Jia Yanran, Shi Juntai, Li Xinghao, Chen Hongfei, Fang Jinhui, Jiao Tingkui, Zang Hong, Wang Ye. Classification and evaluation methods for low -permeability tight gas wells in the Zizhou gas field of Changqing [J]. Geology and Exploration, 2021,57 (3) :0647 -0655.

[9] Liu Xiajie, Ma Junqing, Han Dong, Wang Haiyan, Ma Litao, Ge Dongsheng. Main factors controlling the formation of high quality tight sandstone reservoir in Linxing block, eastern margin of Ordos Basin [J]. Natural gas Geosciences, 2018,29 (04): 481-490

[10] Guo Mingqiang, Zhou Longgang, Zhang Bing, Pan Xinzhi, Wang Yingbin. Gas water distribution characteristics of tight sandstone: a case study of Linxing area in Eastern Ordos Basin [J]. Natural gas Geosciences, 2020,31 (06): 855-864

[11] Ding Wanggui, Liu Shijie, Dong Jianhong, Wang qunchao, Yang Yuguang, Liu Jinhai. Optimization method of low efficiency well measures in Linxing tight gas field in Ordos Basin [J]. Natural gas exploration and development, 2020,43 (02): 88-94