Multi-factor controls on initial gas production pressure of coalbed methane wells in Changzhi-Anze block, Central-Southern of Qinshui Basin, China

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Abstract
Adsorption and desorption of coalbed methane are generally at a dynamic equilibrium state under the undisturbed coal reservoir. However, as the reservoir pressure drops to a certain
value during the extraction of coalbed methane, the equilibrium state is destroyed and thus more coalbed methane desorbs and escapes from coal to wellbore. Here the corresponding bottom-hole fluid pressure is called initial gas production pressure (IGPP) in the development practice of coalbed methane wells. This paper, which has taken Changzhi-Anze block in the central-southern part of Qinshui basin as the study object, addresses the distribution characteristic and control factors of IGPP of coalbed methane wells and then explores the key factors affecting IGPP using grey correlation analysis theory. The results indicate that IGPP varies from 1.09 MPa to 6.57 MPa, showing a distribution law with high in the middle and low in the west and east of the study area, which presents a similar distribution characteristic with burial depth, thickness, coal rank, gas content, original reservoir pressure, and in-situ stress. Further, through grey correlation analysis, it concludes that the correlation degrees of control factors affecting IGPP of coalbed methane wells in the descending order are decline rate of working fluid level, water yield before gas production, reservoir pressure, coal thickness, coal rank, minimum horizontal principal stress, burial depth, and gas content. Among these factors, engineering factors, including decline rate of working fluid level and water yield before gas production, present a key controlling effect, because they can determine the smooth migration pathway directly during initial water production. Another key factor, original reservoir pressure also builds strong and positive correlation with IGPP under the interaction of other geology and reservoir factors, revealing the capability of gas desorption and the transmission of pressure drops.

Keywords
Changzhi-Anze block, coalbed methane, initial gas production pressure, control factors, grey correlation analysis

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Introduction
The exploration and development of coalbed methane (CBM) has spurred in China recently, in order to promote coal mining safety, decline greenhouse gas emissions and increase natural gas supply (Dutta et al., 2011; Karacan et al., 2011; Luo and Dai, 2009; Tao et al., 2013, Wang et al., 2019). CBM is mainly adsorbed on the inner surface of the coal matrix (Busch et al., 2004; Chen et al., 2017; Krooss et al., 2002; Wyman, 1984). Under the original reservoir state (certain temperature and pressure), adsorption/desorption among coal matrix and gas molecules is in a dynamic equilibrium state (Cui and Bustin, 2005; Zhang et al., 2017). During CBM recovery, with continuous drainage and depressurization, the adsorption/desorption equilibrium relationship between coal and gas will be broken when the reservoir pressure drops to a certain value. At this point, more adsorption gas begins to desorb into free gas, then flows into the wellbore unceasingly. Here the corresponding bottom-hole fluid pressure is the initial gas production pressure (IGPP) in the development practice of CBM. Generally, IGPP can be read directly from bottom-hole pressure gauge, which means the sum of the casing pressure, gas column pressure and the liquid column pressure of mixed gas (Yang et al., 2010), as shown in equation (1). Actually, it usually deems that the gas begins to desorb, when the reservoir pressure drops to the critical desorption pressure (equation (2)), which was obtained from the isothermal
adsorption curve based on Langmuir equation (Langmuir, 1980). This critical desorption pressure has been widely applied in determining the reasonable initial drainage system of CBM wells (King, 1993), whereas productive practice shows that there are always differences between these two parameters (Liu, 2013; Ni et al., 2007; Zhu et al., 2018), thus often inducing some troubles to actual production.

\[ P_i = P_b + P_g + P_m \]  
\[ P_{cd} = \frac{V \cdot P_L}{V_L - V} \]

where \( P_i \) is IGPP, MPa; \( P_b \) is the casing pressure, MPa; \( P_g \) is the gas column pressure, MPa; \( P_m \) is the liquid column pressure of mixed gas, MPa; \( P_{cd} \) is critical desorption pressure, MPa; \( V \) is the gas content, cm³/g; \( P_L \) is Langmuir pressure, MPa; \( V_L \) is Langmuir volume, cm³/g.

From equation (2), we could conclude that critical desorption pressure is usually affected by gas content. Thereby, apart from experiment errors, it is mainly controlled by geological factors, such as coal rank, maceral composition, geological structure, etc. These results have been frequently proved in recent years (Crosdale et al., 1998; Laxminarayana and Crosdale, 1999). Actually, CBM removed from micropores must overcome the capillary pressure in the pore channel first. In addition, CBM also needs to overcome the resistance of the pore wall and the viscous force, and other resistances from wellbores and water during gas migration. Hence, IGPP, an important parameter for gas production, is controlled by complex interaction of storage and transport mechanisms (Aminian and Ameri, 2009) causing great changes compared with critical desorption pressure. Thus, investigating the control factors of IGPP could help to build a good relationship between critical desorption pressure and actual situation. However, the research on the key factors of gas production pressure of CBM wells has been reported rarely.

Recently, the commercial breakthrough of CBM production has been achieved successfully in China, especially in the southern part of Qinshui basin (Cai et al., 2011; Li et al., 2015; Lv et al., 2012). Nevertheless, due to the complexity and heterogeneity of geological structure and coal reservoir (Qin et al., 2017), the northern and central parts are still at the initial stage of CBM industry. Changzhi-Anze block is located in the central-southern part of Qinshui basin with widespread deformed coal (Zhang et al., 2017; Zhong et al., 2017), higher in-situ stress and varied burial depth, compared to adjacent areas in the same coal basin, such as Fanzhuang block and Panzhuang block. In the course of the practical exploration and development of CBM in Changzhi-Anze block, there often exists great changes in IGPP, strong heterogeneity in spatial distribution and obvious differences in gas production. Whilst based on previous practice experiences (Zhou, 2016), IGPP of CBM wells frequently varies greatly under the conditions with different tectonic positions, well types or well completion ways. Even with similar gas content, it varies greatly. Hence, investigating the key factors to IGPP is critical to further exploitation and utilization of CBM.

Herein, this paper, taking Changzhi-Anze block as the study area, begins with reviews of geological background and continues with discussions of geology, reservoir and engineering effects on IGPP. Finally, our study aims to evaluate the effect of control factors on IGPP quantitatively by means of grey correlation theory, and then discusses the key factors to
IGPP in Changzhi-Anze block, for raising the concern on the key influencing factors of initial gas production of CBM wells in the study area.

**Geological setting**

**Regional tectonics**

The data analyzed in this work were acquired from CBM wells in Changzhi-Anze block, Shanxi, China. Regionally, Changzhi-Anze block is located in the central-southern part of Qinshui basin with the axis of the Qinshui synclinorium as the boundary, as seen in Figure 1. Therefore, the study area is still a synclinorium basin, which is one of the Mesozoic basins evolved from the Late Paleozoic North China Craton Basin (Su et al., 2005). The structural formations in the study area were affected notably by NE-SW compressional stresses and NW-SE extensional stresses during the Jurassic-Cretaceous Yanshanian Orogeny and the late Tertiary Himalayan movements (Cai et al., 2011; Lau et al., 2017; Li et al., 2017; Qin et al., 2001). Faults and folds, striking NNE and NE, are relatively developed and distributed homogeneously; the main fault is Ergangshan fault in the eastern part (Li et al., 2018; Zhang et al., 2017).

**Coal-bearing strata**

Taiyuan and Shanxi Formations are the two main coal-bearing strata in the study area. Of these, No. 3 coal seam of the Permian Shanxi Formation is the object of this study, and its basic parameters are shown in Table 1. The burial depth of the No. 3 coal seam shows largely varied features, ranging from 529 m to 1423 m with a mean of 939 m. The coal thickness ranges from 0.3 to 7.4 m, with an average of 4.9 m. Commonly, the study area contains semi-anthracite and anthracite coal with vitrinite reflectance \( R_{\text{o,max}} \) between 1.78% and 2.78%. According to the gas desorption tests, gas content of coal reservoir varies from 1.2 to 23.9 cm\(^3\)/g (mean 13.6 cm\(^3\)/g).
Table 1. Basic parameters of No. 3 coal seam in Changzhi-Anze block.

| Parameters |  $A_d$ (%) |  $M_{ad}$ (%) |  $R_{o,max}$ (%) | Burial depth (m) | Thickness (m) | Reservoir Pressure (MPa) | Reservoir Temperature (°C) | Gas content (cm³/g) |  $P_{ad}$ (MPa) |
|------------|------------|--------------|------------------|-----------------|---------------|-------------------------|--------------------------|-----------------|--------------|
| Minimum    | 9.6        | 0.4          | 1.78             | 529             | 0.3           | 1.76                    | 16.7                     | 1.2             | 1.09         |
| Maximum    | 35.0       | 1.5          | 2.78             | 1423            | 7.4           | 11.09                   | 41.5                     | 23.9            | 6.57         |
| Number of samples | 90          | 90           | 88               | 83              | 83            | 41                      | 41                       | 90              | 26           |
| Mean       | 17.4       | 0.9          | 2.32             | 939             | 4.9           | 5.84                    | 30.3                     | 13.6            | 3.13         |

Figure 2. Distribution of initial gas production pressure of CBM wells in Changzhi-Anze block. IGPP: initial gas production pressure.

**Distribution characteristics and effect factors of IGPP**

**Distribution characteristics of IGPP**

In this paper, we collected the data of IGPP, which is defined in the Introduction section, from actual production data of 26 wells in Changzhi-Anze block; it summarizes that IGPP in Changzhi-Anze block ranges from 1.09 MPa to 6.57 MPa, with a mean of 3.13 MPa. From Figure 2, it can be seen that IGPP shows a distribution law with high in the middle and low in the west and east of the study area in the plane. Furthermore, with the analysis of Figure 1, IGPP follows an increasing trend approximately with the increase of burial depth in the vertical.

**Effect of control factors on IGPP**

Gas production depends on the difficulty degree of gas desorption, diffusion and seepage. So IGPP is largely the product of synthetic effect of multi-factors, including geology factors,
reservoir factors, and engineering factors. In this work, nine factors, including geological structure, burial depth, thickness, coal rank, gas content, original reservoir pressure, in-situ stress, water yield before gas production and the decline rate of working fluid level, were analyzed to reveal the effects of control factors on IGPP of CBM wells.

**Burial depth.** As mentioned in the ‘Coal-bearing strata’ section, the burial depth shows a regular distribution with shallow in the east and west and deep in the middle of the study area (Figure 1). Due to control by the morphology of sedimentary basin. In the southern-western part of Anze block and the eastern part of Changzhi block, the burial depth of the No. 3 coal seam is generally less than 800 m, while the axis of Qinshui synclinorium, in the central part of the study area, is mostly with the burial depth of 1300 m. Figure 3 indicates that burial depth has a positive relationship with IGPP in Changzhi-Anze block. With the burial depth increasing, the increased stress could make more fractures closed in different degrees (Meng et al., 2011). Meanwhile, with the increase of the burial depth in the coal seam, the reservoir pressure increases at some extent (Wei et al., 2010). Thus, the growing reservoir pressure and escape distance at the vertical direction are beneficial to gas conservation. All those could help to elucidate favorable conditions for promoting gas desorption with high gas desorption pressure.

**Thickness.** Figure 5 describes that the coal thickness is often less than 4 m, and then it gradually increases from west to east, in the northwest and west of the study area. The coal thickness is more than 6 m when the central part is close to the axis of Qinshui synclinorium, where it correspondingly distributes high values of IGPP. Further, the coal thickness is generally larger in the eastern part of the block with more than 5 m, but IGPP often lies in low values with less than 3 MPa. Simultaneously, dispersed data in Figure 4 prove that thick coal seam could provide some favorable conditions for gas preservation and thus promoting high gas desorption effect, but this positive effect maybe weaken or neutralized by other strong effects.

**Coal rank.** Coal rank ranges from 1.78% to 2.78%, and its spatial distribution shows high values in middle and southern parts in Figure 6. Together with the plot of the relationship between IGPP and coal rank in Figure 7, the spatial distribution of the two parameters...
shows no perfect consistency. Due to the small scale change of coal metamorphism, we observe a weak positive effect on IGPP with an increase in coal rank. In general, with the increase of coal rank, gas content increases with less meso- and macropores (Nie et al., 2015; Okolo et al., 2015), which could provide good reservoir energy. Simultaneously, it is widely thought that the pressure drops are first transmitted to meso- and macropores through fractures in the process of drainage and depressurization (Fu et al., 2007); the existence of weak superposition effect of adsorption potential field brings into gas desorption in meso- and macropores preferentially. Less meso- and macropores may not only enhance the ability of gas preservation but also increase the difficulty of gas desorption.
Original reservoir pressure. Original reservoir pressure ranges from 1.76 MPa to 11.06 MPa with an average of 5.84 MPa, and its spatial distribution shows a similar characteristic with IGPP in Figure 9. Meanwhile, Figure 8 denotes that there is a good relevance between original reservoir pressure and IGPP. Namely, with the increase of original reservoir pressure, IGPP in the study area also increases significantly. The reduction of original reservoir pressure is a prerequisite for desorption of CBM. Reservoir pressure is a sign of reservoir energy, and the ratio of critical desorption pressure to original reservoir pressure reflects the difficulty degree of CBM drainage, depressurization and gas recovery (Cui and Bustin, 2005; Zhao et al., 2015). Moreover, the original reservoir pressure has strong relationship with gas content, influencing the desorption rate of CBM directly (Sang et al., 2009; Yao et al., 2008).
The CBM well with high original reservoir pressure usually means that this CBM well locates in the areas with high gas content and saturation, thus promoting the transmission of pressure drops and increasing the possibility of gas desorption.

Gas content. Figure 10 presents the distribution of gas content with a large variation. As mentioned above, the higher gas content is, the greater the probability of gas desorption is. Then the higher IGPP is easy to appear. However, the correlation between IGPP and gas content may be not notable in Figure 11, since the interaction of other factors also exist, such as structure setting effect, which will be explained later.
Structural setting. Geological structure is through controlling the pore-fracture system in the coal reservoir, to control the gas content and seepage channel in the coal reservoir (Li et al., 2013; Song et al., 2005), thus affecting the gas production. Normal faults affected by extension tectonic stress field, often exist more macro- and mesopores with strong connectivity and open fractures, causing low gas content (Hou et al., 2012; Jiang et al., 2010; Liu et al., 2019). Reverse faults along with more complex pores and fractures, has good gas content, but increase the resistance to gas migration, which could be the reason for high gas content with IGPP. Meanwhile, it is easy to appear deformed coals near faults or at the tip of faults. Hence, we could observe low IGPP value near the Ergangshan fault from Figure 2 and Table 2, such as Q7 and Q8 wells with IGPP value of only 2.26 MPa and 1.78 MPa, respectively. The anticline and syncline are also governed by extension and compression stress fields (Dieterich and Carter, 1969). For example, Q5 is located near the axis of syncline, showing low IGPP values with 1.31 MPa.
In-situ stress. According to the breakdown pressure, shut-in pressure and reservoir pressure of the coal seam, obtained from the injection/fall-off well tests and in-situ stress measurements in the study area, several parameters (e.g. the maximum horizontal principal stress \( \sigma_{h_{\text{max}}} \) and the minimum horizontal principal stress \( \sigma_{h_{\text{min}}} \), etc.) can be calculated to characterize the in-situ stress (Chen et al., 2017; Fairhurst, 2003; Haimson and Cornet, 2003).

\[
\sigma_{h_{\text{min}}} = P_c \tag{3}
\]

\[
\sigma_{h_{\text{max}}} = 3P_c - P_f - P_0 + T \tag{4}
\]

where \( P_c \) is the shut-in pressure, MPa; \( P_f \) is the breakdown pressure, MPa; \( P_0 \) is the reservoir pressure, MPa; \( T \) is the tensile strength of the coal or rock, MPa.

Of these, the minimum horizontal principal stress presents a relatively obvious relationship with IGPP. This relative correlation can be derived by plotting IGPP at different values of the minimum horizontal principal stress in Figure 12. And from Figure 13, the minimum horizontal principal stress lies between 13.5 MPa and 27.5 MPa, and higher values of IGPP are concentrated in the high stress zone of central part. Generally, under the original reservoir condition, coal reservoir stays in a certain and stable environment of stress field. As the stress increases, the permeability decreases exponentially (Gentzis et al., 2008; Liu and Rutqvist, 2010; Meng and Li, 2013; Tang et al., 2015; Zhang et al., 2019). Hence, high in-situ stress provides a favorable condition for CBM preservation and desorption, but may obstruct gas migration with low permeability.

**Table 2.** Characteristics of initial gas production pressure in different structural positions.

| Well number | Burial depth (m) | \( R_{o_{\text{max}}} \) (%) | Initial gas production pressure (MPa) | Gas content (cm³/g) | Structure positions |
|-------------|-----------------|-----------------------------|--------------------------------------|---------------------|---------------------|
| Q5          | 715.0           | 2.10                        | 1.31                                 | 12.72               | Near axis of syncline |
| Q7          | 836.6           | 2.37                        | 2.26                                 | 19.34               | Near fault           |
| Q8          | 728.5           | 2.37                        | 1.78                                 | 18.50               | Near fault           |

**Figure 12.** Relationship between initial gas production pressure and minimum horizontal principal stress.
Decline rate of working fluid level. The decline rate of working fluid level directly controls the bottom-hole pressure of the CBM well. Therefore, the key to the control of CBM well drainage should have an appropriate decline rate of working fluid level. The relationship between IGPP and the decline rate of working fluid level in Figure 14 indicates that IGPP shows varies distribution when the working fluid level drops at a speed of less than 20 m/d. But compared with the fast decline rate (>20 m/d), it may appear higher IGPP easily at relatively slow decline rate. Too fast decline rate of working fluid level is easy to cause severe pressure sensitivity and velocity sensitivity effects.

**Figure 13.** Spatial distribution of minimum horizontal principal stress in Changzhi-Anze block.

**Figure 14.** Relationship between initial gas production pressure and decline rate of working fluid level.
Daily water yield before gas production. The water yield before gas production in CBM wells reflects the liquid supply capacity of reservoir at a certain extent. High water yield indicates that the water content in coal seam is high, or wells are located in the water conducted zone, or fracturing fractures connect the aquifer at the roof and floor of coal seam. The maximum water yield before gas production is up to 31.3 m³/d, with the minimum only 1.4 m³/d in Figure 15. With the increase of daily water yield before gas production, IGPP decreases rapidly and then keeps a low value.

Quantitative evaluation of the effect of control factors on IGPP

Grey correlation analysis

Grey correlation analysis, as an important constituent of grey system theory, is applied to determine whether there exists a close relationship between array curves on the basis of their similarity (Deng, 1985). The more similar the curves are, the larger the correlation degree between the curves is, and vice versa. The above qualitative analysis evaluates the relationships between burial depth, coal thickness, coal rank, gas content, original reservoir pressure, water yield before gas production, the decline rate of working fluid level and IGPP of CBM wells, but it cannot determine the influence degree of the factors on IGPP clearly. In order to analyze the main controlling factors affecting IGPP of the CBM wells in the study area, the grey correlation analysis method is introduced in this paper to quantitatively determine the correlation between each influence factor and IGPP, for objectively evaluating the influence of each factor on IGPP.

Therefore, we suppose \( \{x_0(n)\} \) for reference array, representing the IGPP of each CBM well, and \( \{x_i(n)\} \) for comparative array, representing the corresponding values of each control factor. In order to make the trend of each parameter series more obvious, the initial value method was used to normalize the parameter series (Lv et al., 2012; Zhao et al., 2015). Thus, the correlation coefficient \( \varepsilon_{0i}(k) \) between the reference array and the comparative arrays regarding the CBM well of well number \( k \), could be calculated by equation (5)

\[
\varepsilon_{0i}(k) = \frac{\Delta_{\text{min}} + \rho \Delta_{\text{max}}}{\Delta_{0i}(k) + \rho \Delta_{\text{max}}}
\]
where $\rho$ is the resolution coefficient and usually 0.5; $\Delta_{\text{max}}$ and $\Delta_{\text{min}}$ are the maximum and the minimum value, respectively, of the absolute differences in each comparative array; $\Delta_{0i}(k)$ is the absolute difference between the reference array $\{x_0(n)\}$ and the comparative arrays $\{x_i(n)\}$ in each CBM well.

$$\Delta_{0i}(k) = |x_0(k) - x_i(k)|$$

Due to the dispersion of the correlation coefficient, the correlation degree $R_{0i}$ is proposed to determine the correlation between the comparative array and the reference array, namely the average value of all correlation coefficients of each corresponding comparative array.

$$R_{0i} = \frac{1}{N} \sum_{1}^{N} \varepsilon_{0i}(k)$$

where $R_{0i}$ is the correlation degree between the reference array and the comparative array; $N$ is the array length.

Finally, the correlation degrees of control factors (except structure setting with unable quantitative values) are calculated in Table 3. These factors affecting IGPP of CBM wells in the descending order of influence degree are decline rate of working fluid level, water yield before gas production, original reservoir pressure, coal thickness, coal rank, minimum horizontal principal stress, burial depth, gas content. So we could conclude that engineering factors (decline rate of working fluid level and water yield before gas production) and original reservoir pressure, showing obviously higher correlation degrees than other factors, are the key factors to control the IGPP of CBM wells in Changzhi-Anze block.

### Key factors for initial gas desorption pressure

**Engineering factors.** During initial water production, the effective stress gradually increases with the depressurization and drainage, and pores and fractures in the coal reservoir gradually narrowed (Chen et al., 2015), which leads to the decreasing permeability of the coal reservoir and the increasing resistance of CBM migration. Generally, the decline rate of working fluid level, should be followed the continuous, slow and steady principle in CBM production process (Pashin, 2010). Slow decline rate could cause unnecessary energy consumption in the engineering practice analysis, and the fast decline rate may lead to the

| Factors                              | Correlation degree | Rank |
|--------------------------------------|--------------------|------|
| Decline rate of working fluid level  | 0.7667             | 1    |
| Daily water yield before gas production | 0.7255          | 2    |
| Original reservoir pressure          | 0.6826             | 3    |
| Coal thickness                       | 0.5971             | 4    |
| Coal rank                           | 0.5535             | 5    |
| Minimum horizontal principal stress  | 0.5319             | 6    |
| Burial depth                         | 0.5253             | 7    |
| Gas content                          | 0.5016             | 8    |
phenomenon of spouting sands and powder and a serious damage of permeability. Afterwards, fast pressure drops would follow to cause the sensitivity of reservoir stress and fracture closing (Tao et al., 2013), thus inducing a limited pressure drop funnel and an increasing migration resistance. For instance, there is a fast decline rate of 36.0 m/d in Q22 well (Figure 16(c)) with corresponding IGPP value of only 2.6 MPa. Compared with Q24 well (Figure 16(a)), when its working fluid level drops at 5.5 m/d, its IGPP is up to 6 MPa. Simultaneously, high water yield has an obviously inhibitory effect on CBM desorption. Seeing the production curve in Q20 well in Figure 16(b), there is only 1.96 MPa of IGPP with high daily water yield of 21.8 m³/d. On the one hand, due to the existence of clay minerals, hydration swelling of clay minerals is noticed, reducing the pore diameter in the coal reservoirs. On the other hand, the small particles in the coal reservoir are scattered and migrated in the pore throat, resulting in a blockage phenomenon and inducing the reduction of the permeability of the coal reservoir to hinder the production of CBM. So it appears that the IGPP significantly diminishes with the increase of daily water yield before gas production in the study area.

Additionally, drilling fluid and fracturing operation methods, which cannot participate in the quantitative evaluation, are also important engineering factors affecting the IGPP. Generally, the developed fractures in the coal seam are easy to cause serious filtration loss. Squeeze-injection operation usually adopts the small displacement (lower than 10 m³/h) to inject water into the coal seam, which is difficult to form a fracture with high conductivity in the coal seam, thus hindering the water production and restraining the CBM production. However, conventional fracturing generally adopts large displacement to produce hydraulic fractures with high conductivity, which is conducive to rapid backflow of fracturing fluid and reduces the damage to coal reservoir. Therefore, the different fracturing operation methods are also the main reason for the different IGPP. On the other hand, drilling fluid invasion and solid particles are viewed as the primary damage to the coal reservoir in the process of drilling. The drilling fluid invasion is easy to cause the swelling of coal matrix, so that the diffusion and seepage channel of CBM becomes smaller and the seepage resistance becomes larger, and even the water lock effect occurs, finally inhibiting the CBM desorption. At the same time, because the drilling fluid occupies the adsorption position of CBM molecules, part of the adsorbed gas could change into free gas, thus reducing the gas content and the gas production pressure in the coal seam (Chen et al., 2014; Zhan, 2012). The solid particles mainly come from the drilling fluid itself and the coal powder and rock debris produced in the process of drilling. When drilling into coal seams, the coarse particles in drilling fluid may fill and block fractures, while colloidal particles may enter into the pores of coal matrix, thus increasing the resistance of CBM migration and reducing the gas production pressure (Peng, 2012; Zhang et al., 2013). Totally speaking, drilling could lead to the smaller pore-fracture of coal reservoir and the increasing resistance of CBM migration, thus reducing the permeability of coal reservoir and the gas production pressure.

**Original reservoir pressure with interaction of other geological and reservoir factors.** As mention above, original reservoir pressure is deemed to be a key factor to IGPP. Many practices show that there is a close relationship between the geological factors and reservoir factors, which control the whole CBM occurrence characteristics. For instance, Zhong (2003), Wei et al. (2010) and Meng et al. (2011) have concluded that with the increase of buried depth and in-situ stress, the original reservoir pressure increases. Meanwhile, Scott (2002) and
Figure 16. Production curves in different CBM wells. (a) Q24 well, (b) Q20 well and (c) Q22 well.
Faiz et al. (2007) also have proved that gas content is closely related to coal metamorphism and coal thickness and burial depth. Further, geological structure often affects the gas content and the distribution of in-situ stress. It can be seen that, under controlled by multi-factors, the pore-fracture system of coal reservoir maintains a certain state to form the adsorption/desorption, diffusion and seepage characteristic of the original reservoir. Therefore, it is concluded that the strong correlation between original reservoir pressure and IGPP is established in the study area, which could be also attributed to the interaction of various factors.

In total, critical desorption pressure is mainly affected by geological factors. If this theoretical value is far lower than the IGPP, it may result in too large initial drainage intensity and fast decline rate of working liquid level to extend the depressurization funnel thoroughly. Only the coal seams near the wellbore have been effectively depressurized to promote the desorption of a small part of CBM. Thus, the gas supply source of the CBM well is severely limited. If this theoretical value is far higher than IGPP, it may also cause low intensity of initial drainage to bring unnecessary time and energy consumption. Therefore, combined the engineering factors, analyzing the influence factors for IGPP is helpful to determine the IGPP and then promote to master the production features and establish a reasonable working system.

**Conclusion**

Under the qualitatively analysis of the effect of multi-factors on IGPP of CBM wells, grey correlation analysis was proposed to evaluate control factors quantitatively of IGPP of CBM wells in Changzhi-Anze block using conventional geological and engineering data, for determining the key factors finally. According to the obtained results, the following conclusions can be drawn:

1. IGPP, ranges from 1.09 MPa to 6.57 MPa, with a mean of 3.13 MPa, showing a distribution law with high in the middle and low in the west and east of Changzhi-Anze block, which presents a similar distribution characteristic with burial depth, coal rank, gas content, reservoir pressure, in-situ-stress
2. Burial depth, thickness, coal rank, gas content, original reservoir pressure and in-situ stress main show a positive relationship with IGPP, but water yield before gas production and the decline rate of working fluid level, have a negative relationship with IGPP.
3. Under grey correlation analysis, the correlation degrees of control factors affecting IGPP of CBM wells in the descending order are decline rate of working fluid level, water yield before gas production, reservoir pressure, coal thickness, coal rank, minimum horizontal principal stress, burial depth, gas content. So, engineering factors and reservoir pressure, with the high correlation degrees of larger than 0.6, are considered as the key factors for IGPP in Changzhi-Anze block. We should pay more attention to original reservoir pressure and engineering factors in Changzhi-Anze block for the further development of CBM to make sure a reasonable drainage system.

**Declaration of Conflicting Interests**

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