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Signature of coproduced water quality for coalbed methane development

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ABSTRACT

Coalbed methane is an unconventional natural gas resource with large reserves across the globe. In China, more than four billion cubic meters of coalbed methane are produced per year with large volumes of coproduced water. The various chemical constituents of coproduced water can be used as an exploration tool for coalbed methane development. This study investigated the composition of coproduced water from the lower Cretaceous Fuxin Formation in the Tiefa basin to determine its chemical signature. Water samples were collected from 12 wells in the Beier Mining Area and analyzed for chemical composition. The quality of the coproduced water after hydraulic fracturing is significantly chemically different from pristine formation water. Interplay is present between the gas production rate and the quality of the coproduced water. Wells with high gas production rate coproduce higher total dissolved solids waters that are enriched in sodium, potassium and bicarbonate but depleted in magnesium. This chemical signature may result from more methane generation, more gas production rate, long drainage time and more water production. Infill wells are not always good for the gas recovery of the existing wells because the fracturing fluids can be harmful to the existing wells in terms of the extent of depressurization and the flowing ability. The concentrations of chloride, sulfate, bicarbonate, carbonate and sodium in the fracturing fluids used in the infill wells are different from pristine formation water; therefore, they can act as indicative ions to explain the impact of the hydraulic fracturing of the infill wells on the existing well. Higher levels of chloride, sulfate and sodium and less bicarbonate and carbonate in the coproduced water from the existing wells means that more fracturing fluid from the infill wells, more proppant carried by the fracturing fluid and more pulverized coal produced by fracturing have entered the radius of pressure drop, which is harmful to the depressurization and the flowing ability of the existing wells and represents more harm to the gas production rate of the existing wells. Similarly, a smaller change of the indicative ion concentrations in the existing wells after the fracturing of infill wells means that the fracturing had less of an impact on the gas production rate.

1. Introduction

Coalbed methane (CBM), an unconventional natural gas resource that is being increasingly developed throughout the world (Jin et al., 2015; Kong et al., 2016, 2017; Liu et al., 2015b; Moore, 2012; Pan and Wood, 2015; Zhang et al., 2015), is trapped in some coalbeds by water (Dahm et al., 2011; Rice, 2003; Rice et al., 2008); therefore, water production is inevitable during the CBM recovery process (Moore, 2012; Pashin et al., 2014). The water produced from CBM reservoir contains abundant chemical information. CBM discharge water at the wellhead is called coproduced water. Typical analyses of the coproduced water quality involve pH, concentrations of major and minor constituents, the water type,

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total dissolved solids (TDS) and isotopic analyses of deuterium, oxygen and other elements (Cheung et al., 2009; Dahm et al., 2011, 2014; Li et al., 2016; Mcbeth et al., 2003a; Plumlee et al., 2014; Rice, 2003). The water quality could provide some useful information that would allow us to gain a better understanding of the hydrology and geochemistry that are fundamental considerations in design and construction for CBM recovery (Kaiser and Ayers, 1994; Meng et al., 2014; Pashin, 2007; Rice, 2003; Zhang et al., 2015). The quality of coproduced water could act as a signature in CBM exploration (Van Voast, 2003), but whether it could be used as a tool to analyze and predict the production characteristics of CBM wells still needs further study because the chemical quality of the coproduced water changes dramatically with a number of factors; these factors include the geologic setting, the depositional environment, the hydrogeological background, the biogeochemical reactions, the buried depth, the characteristics of the reservoir, water/rock interactions, and the source and evolution of the water (Moore, 2012; Pashin et al., 2014; Rice, 2003; Rice et al., 2008; Scott, 2002; Van Voast, 2003; Yang et al., 2013; Zhang et al., 2016).

Coproduced waters across the globe often have high concentrations of soluble salts (Bartos and Ogle, 2002; Healy et al., 2011; Jackson and Reddy, 2007; Li et al., 2016; Mcbeth et al., 2003b; Meng et al., 2014; Taulis and Milke, 2013; Van Voast, 2003; Yang et al., 2013; Zhang et al., 2016). Analysis of TDS reveals that sodium, bicarbonate, and chloride make up greater than ninety percent of the total ions in coproduced water. In general, coproduced waters are of either the sodium bicarbonate or sodium chloride type (Dahm et al., 2011, 2014). Major ions including sodium, chloride and bicarbonate and minor ions including calcium, magnesium, and sulfate are present in coproduced waters (Hamawand et al., 2013). If the coals and associated beds were deposited in a continental environment, the major constituents in the coproduced water are generally sodium and bicarbonate (Cheung et al., 2010; Dahm et al., 2011; Van Voast, 2003), and they have lower TDS, higher calcium and magnesium concentrations and lower sodium and potassium concentrations than marine or marine - transitional environments (Dahm et al., 2011). Nevertheless, if the coals and associated beds are deposited in marine or marine - continental transitional beds, the water quality would be much different from that in a continental deposit (Dahm et al., 2011; Plumlee et al., 2014; Van Voast, 2003).

The chemical data from coproduced water could provide insight into the evolution of the movement of the underground water (Flores et al., 2008; Owen et al., 2015; Rice, 2003). In general, shallow groundwater is of the Ca - Mg - Na - SO_4 - HCO_3 water type with lower TDS (Rice et al., 2008; Yang et al., 2013), while the groundwater in deeper areas has lower calcium and magnesium concentrations and a higher sodium concentration (Taulis and Milke, 2013). The coproduced water from wells nearer to recharge areas has lower sodium and chloride concentrations and higher calcium and magnesium concentrations compared with wells nearer the discharge areas (Van Voast, 2003).

The water quality could be a signature for the gas and water production rate. The well is an unlikely producer of methane if the dissolved sulfate content exceeds 10 meq/L (Van Voast, 2003). Less sulfate, low concentrations of calcium and magnesium, and higher concentrations of sodium, bicarbonate and sometimes chloride are common in the coproduced water from wells with high gas production rates (Kinnon et al., 2010; Van Voast, 2003).

PH has a strong influence on the microbial activity and survival of methanogens, thus it could affect the formation of the biogenic coalbed methane (Bao et al., 2016; Cuzin et al., 2001). The impact of pH on some ions is obvious; for instance, the equilibrium between CO_2, HCO_3 and CO_3^{2-} is determined by pH (Taulis and Milke, 2013).

Nearly all studies regarding the water quality associated with CBM are based on coproduced water. However, the coproduced water is not necessarily the same as pristine formation water, especially when thousands of barrels of hydraulic fracturing fluid is injected into the formation (Huang et al., 2016; Liu et al., 2015a; Plumlee et al., 2014). In a well where hydraulic fracturing is used, the coproduced water is a mixture of fracturing fluids and formation water. The impact of the fracturing fluid on the coproduced water quality should not be neglected. In these cases, further study is needed to explore the signature of the coproduced water quality.

Well pattern development is common in coalbed methane development because wells help each other via interference and because it makes water drainage more efficient and consequently gas desorption and gas recovery in the area are facilitated (Salmachi et al., 2013). Infill wells are new wells constructed in the existing well pattern to reduce well spacing and strengthen well interference to boost gas production rate and shorten the production time. The fluids injected with great pressure from infill wells may affect the drainage of neighboring existing wells. Therefore, a detailed study of coproduced water quality is necessary to assess the impact of the hydraulic fracturing of the infill wells on the existing wells.

We collected fifty-five samples of coproduced water. The purposes of this article are to identify the specific chemical character of the coproduced water and determine the signature of coproduced water quality; we also intend to examine the relationship between changes in ionic concentration and the impact of the fracturing of infill wells on the existing wells.

2. Methods

2.1. Study area description

The Tiefa Basin is a continental faulted basin of Mesozoic sediments in northeast China that encompasses an area of approximately 513 km^2. The CBM development in the Tiefa Basin is centered at Daxing Mine. The mine operators built 31 fracturing wells from 1997 to 2011; among them, fourteen wells are located in the Beier Mining Area, which is our study area, as shown in Fig. 1. The completion depths of the CBM wells within this area are between 700 m and 950 m, the peak gas production rate of the CBM wells reached 12,511 m^3/d, and the cumulative drainage resources in 2011 were approximately 11.42 million m^3.

The Beier Mining Area is folded by an anticline and the lateral continuity of the seams is broken by several normal faults, as illustrated in the floor contour map shown in Fig. 1. The tectonic setting is such that the Beier Mining Area is an area of independent hydrogeology.

In the study area, CBM is produced from two bituminous coal seam groups in the Fuxin Formation that belong to lower Cretaceous strata in Mesozoic sediments, whose overlying strata include the Quantou Formation of lower Cretaceous strata in Mesozoic and Quaternary age unconsolidated sediments. Fig. 2 shows the stratigraphy and hydrostratigraphy of the Beier Mining Area from the Cretaceous to the Quaternary. The Fuxin Formation consists of four units: the glutenite section at the bottom (K_1f_1), the lower coal seam group (K_1f_2), the sand-mudstone section in the middle (K_1f_3), and the upper coal seam group (K_1f_4). More than 10 seams are distributed within the two coal seam groups; the average thickness of the upper seam group is approximately 200 m, and the lower seam group thickness is approximately 160 m. The coal seam group is confined by two impermeable units (mudstones or shales) situated on the top and the bottom of the coal seam group, as shown in Fig. 2. The aquifer that affects the coalbed methane dewatering is the coal bearing strata, which are primarily composed of mudstone, siltstone, coalbeds and sandstone. The permeability of the aquifer is weak.