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Hydrogeological condition patterns of Kuznetsk Basin coalbed methane fields for estimating hydrodynamic calculations

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Abstract. The paper describes the natural regional conditions and key formation factors of groundwater dynamics. Characteristic hydrogeological structure elements for Kuznetsk Basin coal were identified providing parameter-oriented hydrodynamic calculations and hydrogeological models in predicting coalbed methane mining impact on the regional groundwater.

1. Introduction

A number of potential productive coalbed methane (CBM) areas have been isolated in the Kuznetsk Basin. These areas are concentrated in south Kuznetsk Basin within Erunakovsk, Tersinsk, Tutuyassk and Tom-Usinsk mining areas. Basically, these potential mining areas are confined to the brachysyncline flanks, due to relatively coalbed accessibility within the structures not subjected to weathering. Methane is accompanying - gas in coalbeds as it is generated throughout all coalification stages of organic sediments and being sorbed by parent material under proper thermodynamic conditions.

Predominately, CBM is a hazard factor in deep coal mining. Drainage and coal - seam uncovering disturb “in place” conditions and furthers methane desorption which subsequently migrates into low-pressure area, i.e. mining areas. In this case, coal producers have been dashing via underground mine ventilation. Nowadays, due to many mining techniques CBM extraction is possible before underground pit construction. This mining method is based on the identified methane properties- desorption and migration after releasing hydrostatic pressure. In this case, CBM extraction involves exposed gas seams, hydraulic fracturing to improve permeability and then in-mine pumping of formation water. As a result groundwater pressure decrease generates coal methane desorption, either dissolved or free base, migrating to the borehole. In view of this specific feature, CBM by borehole mining is inevitably accompanied by the extraction of formation water to the surface. This defines the significant hydrogeological aspects of coal-methane mining**.** At the stages from pilot commercial mining to extensive production, it is important to forecast the influence of new production activities on underground hydrosphere and adjacent spheres of subsurface resources.

2. Physicogeographical conditions

Hydrodynamic conditions of Kuznetsk Basin formed as a result of the interaction of various natural and anthropogenic factors. The physicogeographical conditions of studied region and influence factors on the groundwater dynamics, as well as CBM mining areas are discussed.

Kuznetsk coal basin, an intermontane basin, is located in central Eurasia: in the N-W Altai-Sayan folded zone, near West Siberian Plain border. Th**e** infrastructure for CBM by borehole mining is being developed within the central southern basin province.

Climate

The Kuzbass climate is continental, being determined by its geographical position. The climate is characterized by long and cold winter and short and hot summer. Average annual temperature is 0°C, varying between −50°C in January to +35°C in July. Total annual precipitation is about 750 mm of average normal 500 mm, whereas groundwater recharge is 100 mm/yr. Two-meter snow cover reduces

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ground freezing depth to 0.2-0.4 m. In general, the excessively humid climate provides favorable conditions for groundwater recharge.

Terrain

The Salair and Kuznetsk Alatau mountain systems, extend meridionally along Kuznetsk Basin border, preventing Arctic and Atlantic air mass circulations, which, in its turn, determines the climate pattern of this region. Geomorphological conditions of the Kuznetsk Basin are different, including 5 landscape zones. The studied region is situated in dissected low-mountain topography, where elevation levels between watershed divide and water course is 300 meters and the sea level varies from 180 m to 580 m. Wide watershed areas include dissected relief. The river valleys are colateral to the mountain bordering of basin indicating their neo-tectonic origin. The relief and the landscape features form favorable conditions for groundwater recharge.

3. Geological structure and lithological description

Regional geological structure and tectonic conditions determine distinctive features of the hydrogeological stratification, as they govern the subsurface filtration heterogeneity. Studying hydrodynamic conditions of CBM fields, it is very important to consider the middle and upper structural levels of the basin deposits, which are comprised of coal formation and overlying rocks.

Upper Permian (P_2) coal formations of the Kolchugino series, composed of the middle structural level are prospective for CBM mining. Kolchugino series is subdivided into Ilyinsk (P_2il) and Erunakovsk (P_2er) subseries and suites. Total coal formation thickness is more than 2000 m, while overall thickness of coal layers is about 320 m.

Lithological composition of Kolchugino series includes sandstone, aleurolite, argillite and coal. Aleurolite is more abundant, up to 60% and sandstone up to 24% within the cross-section. Lithological variations are changeable, whereas composition and thickness vary spatially lateral. Sandstone layers are rather continuous, the thickness of which reaches 50 m. Coal beds are irregular geometrical shapes: pinching-out, branching or merging.

Coal-bearing deposit structures are various. Sandstone thicknesses are characterized by cross bedding and / or swaley-cross bedding. Aleurolites exhibit cross and/or or horizontal bedding, while argillites exhibit poor horizontal bedding including layers of insignificant thickness, confined to surface coal beds. Coal beds exhibit distinct horizontal bedding and cleavage, i.e. non-tectonic fracturing. This property determines high coal bed permeability comparable to adjacent rocks.

Kolchugino series deposits are characterized by layered structure, with alternating lithotypes of different permeability. The thickness is composed of numerous small amplitude discontinuous fractures.

Upper structural level deposits do not include coal beds suitable for methane mining. Nevertheless, the authors consider these deposits to be of interest in terms of hydrodynamic structure elements. Upper structural level basin deposits include Triassic (T), Jurassic (J) and Quaternary (Q) deposits.

All bedding rocks are lithified and involve regional diagenetic or tectonic fracture system. Fracture system intensity and openness are irregular vertically and horizontally and are defined by rock stress and strain state. Highly-developed fracture openness is found in the upper cross-section at a depth of 100-150 m. This factor significantly influences the formation of regional hydrodynamic conditions.

4. Hydrogeologic characteristics

As mentioned above, the middle and upper structural levels of the Kuznetsk Basin deposits are considered being practical in studying the hydrodynamic conditions of the CBM fields. Based on lithologic-stratigraphical and hydrodynamic features the following four geological units were identified:

Aquifer system of Quaternary alluvial deposits – phreatic continuous aquifer, confined to river deposits the thickness of which varies from 0 to 10 meters. Groundwater is pore-stratal with free surface or weak artesian pressure.

Aquifer system of Jurassic deposits – located within limited areas of some syncline structures thickness of which is from 0 to 800 m. Jurassic rocks have high active porosity due to less compaction and diagenetic changes comparable to Perm deposits, resulting in rather high water inflow. According to movement, groundwater is either fissure and fissure-stratal, generally unconfined.

Aquifer system of Triassic deposits is within the Kyrgay-Ostashkinsky syncline, the thickness of which is about 570 m. Water inflow system is irregular, where groundwater is fissure and fissure-stratal, unconfined.
Aquifer system of Permian deposits is everywhere, the thickness of which is more than 2000 m. Water inflow system is irregular, where groundwater is fissure and fissure-stratal. The most permeable zones are in cross-section of prevailing sandstone and less permeable aleurolite and argillite. Coal bed permeability is significantly higher than the permeability of adjacent rocks. Graded deposit interbedding with different permeability determines the filtration heterogeneity of coal-bearing deposits. The reservoir pressure increases with depth.

Table 1. Vertical hydrodynamic zoning.

Water exchange zone	Thickness, m	Depth, m	Open rock porosity, %	Filtration coefficient Ff, m/day	Mineralisation, gr/l
Active	10-150	< 150	5-15	0,1-1,0	<1
Moderate	more than 2000	-	2-7	0.001-0,4	0.7-8

Vertical hydrodynamic zoning (table 1) within studied area is governed by various degrees of rock fracturing and fracture poenness at different depths. All bedding rocks are disrupted by regional fracture system of various genesis. Fracture openness and, consequently, rock permeability decrease with the depth [6]. In this case, there are two zones with various intensive groundwater circulation within this region cross-section: active water exchange zone and slow water exchange zone. Active water exchange zone is characterized of lateral hydrodynamic heterogeneity. Maximum rock permeability was revealed within the branched zone system fracture openness which coincides with the river network structure.

5. Data and procedures

Interpretation of CBM field hydrogeological conditions is based on field research materials [6, 7], analysis of previously published data, key reference literature [1, 2, 5, 12], scientific publications [3, 4, 13] and production reports, as well as similar target researches [9, 10, 11, 12]. The exploration results of coal, coalbed methane and groundwater in Erunakovsk, Tutuyassk and Tom-Usinsk mining areas. Hydrodynamic sampling data is the target of this research. The applied methods are based on the key principles of groundwater dynamics [8].
Natural and technogenic condition patterns for hydrodynamic modeling includes determining time mode, spatial structure and areal filtration characteristics within initial-boundary conditions. Based on the analysis results of physiogeographic features, geological structure and hydrogeological characteristic of the studied area, the main hydrodynamic structure elements were determined. The following determined parameters are necessary for developing geofiltration models of CBM fields and analytical calculations.
Decomposition of the filtration area including a set of standard elements was conducted in the following sequence:

1. detecting basic elements in filtration area.
2. determining initial-boundary conditions for each element.
3. evaluating generalized element characteristics, determining range and average values for each parameter.

6. Results and discussion

Hydrogeological conditions of the studied area are governed by the cumulative effects of natural and anthropogenic factors. Increasing development of anthropogenic activities further the significance of the technogenesis itself , which, in its turn, could change this or that nature component. Climatic, landscape and geological factors determine groundwater recharge and discharge regimes, forming the hydrodynamic conditions of considered territory. The climate and relief contribute to the active groundwater recharge which are subjected to intensive seasonal fluctuations. The fluctuation amplitude of seasonal groundwater table level decreases with the depth. Evaluating hydrodynamic processes in the moderate water exchange zone, groundwater recharge value could be constant. The infiltration in this area is about 15% of atmospheric precipitation [1]. During a year these aquifer systems embrace about 100 mm precipitation layer throughout the recharge area.

Table 2. Filtration area parameters.

Water exchange zone	Element	Filtration coefficient Ff, from-to (average), m/day		
		a Q$_{1-4}$	***J$_{1-2}$***	***P$_{1-2}$***
Active	Valleys	10-70 (30)	1-50 (20)	0.3-1 (0.5)
	Slopes		0.1-1 (0.5)	0.05-0.3 (0.1)
	Watersheds		0.01-0.1 (0.05)	0.01-0.1 (0.05)
Moderate	Exploited layer			0.001-0.04 (0.01)
	Adjacent rock thickness		0.01 lateral 0.001 in cross-section	

Geological factors determine the filtration flow structure and intensive water exchange. The geological structure features and regional tectonic conditions of the region exhibit distinct vertical hydrodynamic zonation section (tables 1, 3) and lateral filtration heterogeneity which could be traced in active water exchange zone (table 2).The regularities are: decreasing section permeability with the depth (table 1). In the active water exchange zone most permeable rocks are confined to the valleys of surface stream flows, comparable to watershed areas which are characterized by significantly less permeable rocks [7].

Coal-bearing beds at considerable depths are characterized by sharp filtration heterogeneity, which is conditioned by different permeability variations of the layers (Ff = 0.001-0.04 m/day) composing the section thickness. The rock permeability in the moderate water exchange zone is vertically less than in subhorizontal direction confined to the surfaces of the lithologic boundaries. Thus, vertically, section permeability is governed by low permeable layers (from 0.001 m/day), and subhorizontally - permeable ones (up to 0.04 m/day) [7].

So, the section of coal-bearing deposits including graded interbeddings of argillite, aleurolite, sandstones and coal beds could be depicted as single-layer thickness with vertical and horizontal inhomogeneous permeability.

Table 3. Hydrodynamic structure elements of coalbed methane deposits.

Water exchange zone	Element	Boundary conditions	Notes
Active	Watershed	II, Q = 0	Suitable for establishing of filtration area boundaries
	Stream flow	III, H = const	
	Terrain	II, Q = const	Infiltration recharge
	Bottom border	II, Q = 0	Conventional impenetrable
Moderate	Borehole	I, H = const, Q = f(t)	Pumping parameters
	Upper boundary	I, H = const	Conventional defined, beyond pumping influence zone.
	Bottom boundary	II, Q = 0	
	Model perimeter	I, H = const	

Groundwater regime in the active water exchange zone is subjected to seasonal fluctuations, which are connected with the change of recharge and discharge conditions during a year. This can be clearly identified by the influence of river network and watersheds and infiltration stream flow (table 3). Modeling active water exchange zone is possible as a single-layer thickness exhibiting zonal permeability increase from watersheds to valleys. Perimeter of the modeled area could be confined to the 2nd and 3^{d} boundary types.

Moderate water exchange zone, where CBM beds are located, do not exhibit noticeable influence of the recharging hydrodynamic boundaries. Due to the remoteness of the recharge and discharge areas decrase the influence of the lateral boundaries. The influence of hydrodynamic interaction decreases with the depth due to the significant thickness of low permeable deposits, separating the coal bed from the active water exchange zone and surface water. In this case, the developed thickness could be modeled as unlimited and limited in the layer cross-section.

7. Conclusion

The analysis of physiogeographic characteristics, geological structure and hydrogeological conditions of the central southern Kuzbass allows formulating the principles of hydrodynamic generalization of CBM production fields and exhibits the following results:

1. determined major regime-forming factors and conditions of their interaction;
2. identified initial-boundary conditions for task-solving;
3. identified regularities of the heterogeneous structure in filtration area; proposed interpretation methods of this heterogeneity in analytic models; and
4. enumerated hydrodynamic structure elements and their characteristic properties.

Proposed concept of hydrodynamic conditions in CBM field is important in the development of numerical hydrogeological models for solving prospecting tasks to determine the hydrodynamic behavior of coal methane wells and assess their possible influence on other hydrosphere targets. Generalized parameters of filtration area and elements of hydrodynamic structure (tables 2 and 3) could be used at the formation stage of conceptual CBM field model. These parameters should be determined in terms of model calibration based on factual observations of the groundwater regime on a modeled object.

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