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Physical aspects of methane mass transfer in well influence zones when degassing coal seams

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Abstract

Introduction. *Gas control and aerological safety of high-performance coal mining in mining faces is possible only after qualitative preliminary degasification, which requires a detailed study of methane mass transfer in well influence zone.*

Research aims *to simulate the processes of methane mass transfer to well's exposed surface based on coal mass gas-dynamic state detailed study, taking into account the variable values of gas content along its length and unit segments exposure time. The summation of gas volumes released from each well segment in a definite time will characterize the total flow rate of a well for the same period. This allows a more soundly based design of coal seams preliminary degasification.*

Methodology. *Modern methods of coal seam degasification design do not take into account differentiated gas emission over the length of the well only using its total flow rate. However, the structure of total flow rate of gas into the well reveals the unevenness of initial gas emission from each unit segment depending on its distance from the wellhead; it creates general unevenness of gas yield over the length of the well until it enters the zone of steady gas pressure and gas content. The present article proposes a mathematical simulation method for a complex gas-dynamic process of methane mass transfer in the radial filtration mode within a circular power loop in a massif and a similar flow path in a well.*

Results. *The proposed method will make it possible to calculate the total flow rate of gas from coal seam near-wellbore zone and thereupon determine its residual gas content as well as develop the methods of coal seam degasification design.*

Key words: *well; coal seam; gas flow rate; gas permeability; gas pressure; gas content; radius of influence, filtration.*

Introduction. At the present time coal seams preliminary degasification prior to mining is the only way to ensure normal air-gas condition of coal mines. It makes it possible to maintain permissible concentration of methane, allowed by *Safety Regulations*, in the outcoming jets of working and development faces equal to 1% by means of reduce gas emission out of the mined seam and its leaders.

It should be noted that in the process of coal bearing strata formation, the associate methane has been creating continuous chemical binding with coal by mean of sorption; as a result, the volume of gas sorbed by one ton of coal has been growing continuously with the growth of pressure. As a result, today, natural gas content in coal seams is a few tens of cubic meters per ton of coal. In particular, in Kuzbass at the attained depths this value may reach 20–30 m^3/t. At the same time, in accordance with *RF Government Decree no. 315 of 35 April 2011 "On the Permissible Levels of Hazardous Gas (Methane) Content in a Mine, Coal Seams and Goaf, Requiring Obligatory Degasification if Exceeded"* a coal seam can be mined if natural gas content is reduced to 13 m^3/t. This standard obliges almost all Kuzbass mines to fulfill preliminary degasification by wells of various orientations in coal massifs.

A well creates internal exposed surface in a massif through which gas yields from the seam over the whole surface of a well as a fissure filtration by means of different pressures in a well and in a massif. Numerous observations at wells in various mining and geological conditions of Kuzbass make it possible to obtain a typical curve of methane flow rate as a function of time (fig. 1) [1–3].

Taking into account different time of exposure for various segments of a well at drilling, it can be stated that total methane flow rate into the well represents the sum of gas volumes escaped from the unit segments of its length which increase as far as they intrude into the massif (q_1, q_2 … q_i) and become stable at entrance to the zone of the established natural gas content (q_{max}). However, these components cannot be identified at the total flow rate of gas metered at the wellhead, for that reason it is necessary to use the method of mathematical simulation [4].

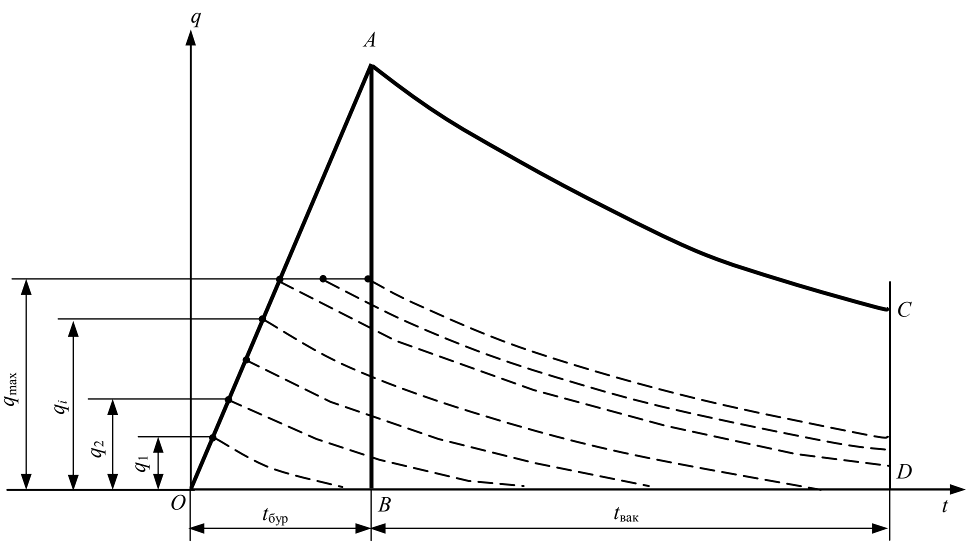

Fig. 1. Typical gas flow rate into the well (*OACD*) and its components (q_1, q_2 ... q_i, q_{max})
Рис. 1. Типовая кривая дебита газа в скважину (*OACD*) и ее составляющие (q_1, q_2 … q_i, q_{max})

As it has been mentioned before, the factor which initiates gas motion in a coal seam is the difference of pressures at the power loop and flow path represented by the internal surface of a well. Fig. 2 shows the character of gas pressure and its gradients variation in near-well-ore zone of a massif in various time points.

Gas will escape into the well until the balance between the pressure gradient and massif's resistance to gas motion is set. This distance can be considered the limiting radius of well influence, formed under $t = \infty$ [5].

As soon as pressure gradient in radial direction from the axis of a well is the main initiator of filtration flow of gas towards the well, the speed of its filtration in a massif, m/s, can be calculated with Darcy's formula [6–8]:

$$v = -\frac{k}{\mu}\frac{dp}{dl}, \quad (1)$$

where k – the coefficient of coal gas permeability, m^2; μ – methane kinematic viscosity, Pa · s; dp/dl – pressure gradient, Pa/m.

At that it should be taken into account that pressure gradients at various segments of a well are not the same and are formed depending on the pressure which has formed in the given area of the massif near the mine working, from which the well is drilled. Thus, gas pressure gradients along the axis of a well will be a variable value, consequently, methane filtration speed changes as far as the depth of well increases. All these factors make methane mass transfer more complex in the zone of well influence which makes it impossible to study it by an experiment. The proposed mathematic model will make it possible to obtain adequate reflection of the gas-dynamic processes around the well, allowing to calculate the flow rate of gas as a function of its length, drilling speed and the time of operation, with the purpose of further coal methane utilization [9–11].

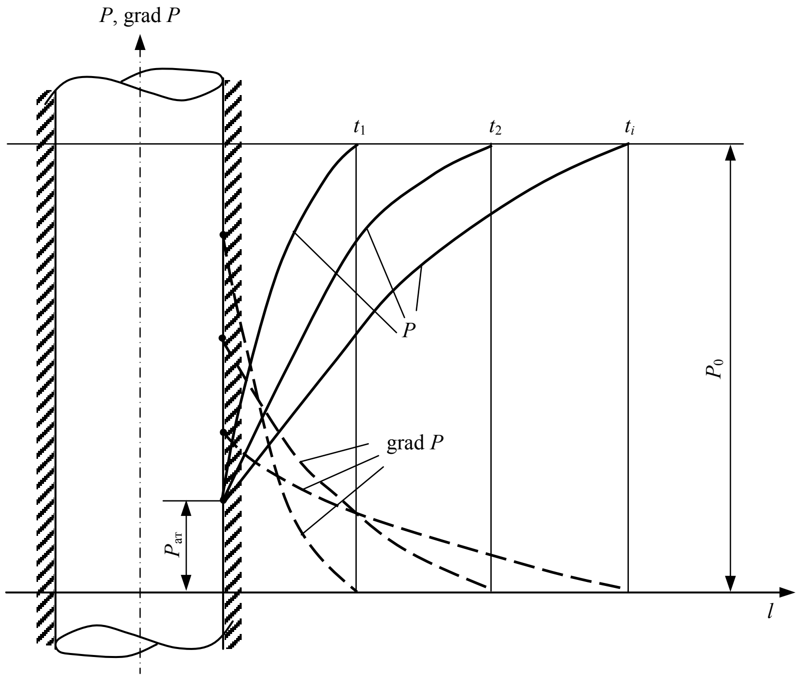

Fig. 2. The change in gas pressure and its gradients in the near-wellbore zone of the array at different time points
Рис. 2. Изменение газового давления и его градиентов в прискважинной зоне массива в разные моменты времени

Mathematical model development. As soon as the face of a well crosses the zones of coal massif with various natural gas content in the process of drilling, its value in any time point will be the function of time $x = f(t)$, which will be equal to x_0 under $t = 0$, and correspondingly, equal to x_1 under $t = T$.

Then

$$x(T) = kt + x_0,$$

where

$$k = \frac{x_1 - x_0}{T},$$

or

$$x = \frac{x_1 - x_0}{T} t + x_0,$$

where T – the total time of drilling.

Gas flow rate as a function of time is described by the following expression

$$q(t) = \int_0^t f(s) ds \quad \text{under } 0 \le s \le t. \tag{1}$$

On condition that

$$f(0) = f(T - t);$$
$$f(t) = f(T),$$

we will get

$$f(s) = f(T - t + s) = kz + x_0,$$

where $z = T - t + s$.

Then

$$f(s) = k(T - t + s) + x_0 = kz + k(T - t) + x_0. \tag{2}$$

Taking into account (2), expression (1) will be:

$$q(t) = \int_0^t f(s) ds = \int_0^t (ks + k(T - t) + x_0) ds. \tag{3}$$

Having integrated expression (3), we will get

$$q = (kT + x_0)t - \frac{kt^2}{z}. \tag{4}$$

Equation (4) describes the law of gas emission into the degassing well during the process of drilling.

In real conditions of mine operation, at coal seams preliminary degassing, the factor of time cannot always be an argument because the process of drilling can interrupt for various reasons [12].

In this case it is reasonable to use the length of a well as an argument, which results in the increase in its internal gas yielding surface area.

Having assumed that

$$x_0 = q_0 e^{\beta t}; \qquad x_1 = q_0 e^{\beta T},$$

we will get

$$\beta T = \ln \frac{x_1}{x_0},$$

or

$$\beta = \frac{\ln x_1 - \ln x_0}{T}.$$

Gas flow rate, described as a function of well length, and, consequently, the area of its internal surface, can be described by the following function

$$q(t) = \int_0^t f(s)ds, \tag{5}$$

where $T(s) = f(T - t + s) = q_0 e^{\beta z}$.

As soon as $z = T - t + s$, then, substituting its value into formula (5), we will get

$$q(t) = \int_0^t q_0 e^{\beta(T-t)} e^{\beta s} ds. \tag{6}$$

Equation (6) describes the law of gas flow rate behaviour in a well in time. Having integrated expression (6) in time within the preset limits, we will obtain the total value of capped methane for a certain period. This, in its turn, can be a basis for the determination of a required number of wells at coal seam degasification, which will provide the guaranteed reduction in natural gas content down to the preset values.

Conclusion. The proposed approach using the method of mathematical simulation of a complex gas-dynamic process of methane mass transfer in mine workings and wells makes it possible to develop the methods of coal seams degasification design.

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Физические аспекты массопереноса метана в зонах влияния скважин при дегазации угольных пластов

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Реферат

Введение. *Управление газовыделением и обеспечение аэрологической безопасности при высокопроизводительной добыче угля в очистных забоях возможно только после качественно проведенной предварительной дегазации, для чего требуется детальное изучение массопереноса метана в зоне влияния скважин.*

Цель работы. *На основе детального изучения газодинамического состояния угольного массива смоделировать процессы массопереноса метана к обнаженной поверхности скважины с учетом переменных значений газоносности по ее длине и времени обнажения единичных отрезков. Суммирование объемов газа, выделившегося с каждого отрезка скважины за определенное время, будет характеризовать общий дебит скважины за тот же период. Это позволит более обоснованно осуществлять проектирование предварительной дегазации угольных пластов.*

Методология. *Современные методы проектирования дегазации угольных пластов не учитывают дифференцированного газовыделения по длине скважины, а оперируют ее общим дебитом. Однако в структуре общего дебита газа в скважину фиксируется неравномерность начального газовыделения с каждого единичного отрезка в зависимости от его расстояния от устья скважины, что создает в целом неравномерность газоотдачи по длине скважины до тех пор, пока она не войдет в зону установившегося газового давления и газоносности. В статье предложен метод математического моделирования сложного газодинамического процесса массопереноса метана в режиме радиальной фильтрации в пределах кругового контура питания в массиве и аналогичного контура стока в скважине.*

Результаты. *Предложенный метод позволит рассчитать общий дебит газа из прискважинной зоны угольного пласта и на этой основе определить его остаточную газоносность, а также усовершенствовать методики проектирования дегазации угольных пластов.*

Ключевые слова: *скважина; угольный пласт; дебит газа; газопроницаемость; газовое давление; газоносность; радиус влияния; фильтрация.*

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