第 36 卷第 9 期　　煤　炭　学　报　　Vol. 36　No. 9
2011 年　9 月　　JOURNAL OF CHINA COAL SOCIETY　　Sep.　2011

优秀博士学位论文摘要

论深部煤层气成藏效应

申　建[1,2]

(1. 中国矿业大学 资源与地球科学学院，江苏 徐州　221116；2. 中国矿业大学 煤层气资源与成藏过程教育部重点实验室，江苏 徐州　221008)

摘　要：从理论上分析了深部煤层气成藏的特殊性，系统阐述了煤层含气性、渗透性及流体压力系统的特征及其地质控制因素。研究认为：受地应力机制转换，深部煤层天然裂隙的产状和组合模式存在垂向分带性，进而影响到煤层渗透率的发育状况。构建了基于温压条件下吸附收缩膨胀、热膨胀、地应力及地下水化学等效应深部煤层渗透率数学模型，分析了深部煤层渗透率的分布规律。建模分析了地应力场、地温场及煤基质收缩膨胀效应对煤层压力状态的控制作用，发现深部煤层与浅部煤层的成压因素差异显著。在埋深 1 200 m 以浅，地应力和吸附量增加诱导的流体压力增强效应基本相当，地温效应最弱；埋深继续增大，地温效应变强，地应力次之，吸附膨胀效应最弱。

基于较高温压条件下的煤吸附 – 解吸物理模拟，揭示了深部地层条件下煤吸附行为的特殊性。研究发现：埋深增大，煤级对煤吸附性的影响减小，高煤级煤吸附性对储层压力的敏感性弱于低 ~ 中煤级煤。构建了耦合煤级 – 温度 – 压力的有效扩散系数模型和深部煤层含气量数学模型，发现深部煤层含气量与埋深之间的“临界深度”受煤级、地层温度、地层压力的综合控制，临界深度在同煤级条件下随储层压力梯度增大而变浅，在相同煤级和储层压力梯度条件下随地温梯度减小而变深。认为临界深度以浅的地层压力对煤层含气量影响更为显著，临界深度以深则温度起着更为重要的控制作用。

基于温压条件下的流固耦合实验，初步揭示了深部煤层力学性质和渗透性的特殊性及其地质影响因素。研究发现：无论煤级如何，围压均是影响煤岩力学性质最显著的因素；流体压力对较低煤级煤力学性质的影响相对较大，温度对较高煤级煤力学性质的影响似乎更为显著。以此为基础，进一步构建了深部煤岩力学性质预测模型。发现煤岩渗透率与有效应力、弹性模量、泊松比均呈负指数关系，温度对煤岩渗流能力的影响受控于煤级且极为复杂。通过三步加载地质因素，导出了吸附 – 温度 – 应力 – 流体压力效应耦合的深部煤层渗透率数学模型。

研究提出了深部煤储层流体压力预测的“压力梯度校正系数法”，构建了深部煤层气成藏效应预测的三元指标体系和模型。应用该套方法体系，对鄂尔多斯盆地东部的深部煤层气成藏效应进行分析，发现存在 3 种有利成藏组合方式和 18 种较有利组合，并预测了其区域分布规律。

关键词：深部煤层气；成藏效应；控制因素；数学模型

基金项目：国家重大科技专项资助项目(2008ZX05033 – 003)；国家自然科学基金重点资助项目(40730422)

作者简介：申　建(1983—)，男，四川遂宁人，讲师，博士。E – mail：cumtshenjian@126.com

CBM-reservoiring effect in deep strata

SHEN Jian[1,2]

(1. *School of Resource and Earth Science, China University of Mining and Technology, Xuzhou 221116, China*; 2. *The Education Ministry's Key Laboratory of the CBM Resources & Accumulation Process, China University of Mining & Technology, Xuzhou 221008, China*)

Abstract: Specific characteristics of deep CBM reservoiring in theory was analysed, and deep CBM content, permeability and fluid pressure properties and their geological controlling factors was systematically eluicdated. Due to the geostress mechanism transform, fracture occurrence and pattern were vertically zonated leading changes of coalbed permeability. Permeability models of deep coalbed incorporated respectively with swelling/shrinkage sorption, earth temperature, geostress and groundwater chemistry effects were constructed to analyse their occurrences. The models was established for analyzing effects of geostress, earth temperature and swelling/shrinkage on fluid pressure, and the significant differences among pressure constitutes between deep and shallow coalbeds was found. The fluid pressure induced by sorption and geostress are roughly equal with burial depth shallower than 1 200 m, and that induced by temperature is the weakest. With burial depth deeper than 1 200 m, effect of earth temperature on fluid pressure is ranked first, geostress ranked second and the weakest is that of coal matrix swelling/shrinkage.

Sorption experiments under high pressure and temperature have revealed particularity of sorption. The study uncoveres that coal rank effect on sorption decreases with increasing burial depth and sensibility of sorption of high rank coals to reservoir pressure are lower than that of low to middle rank coal. Coupling factors of coal rank, temperature and reservoir pressure, effective diffusion coefficient and deep CBM content prediction models are construt. The model reveales that "critical depth" exsits in relationship between CBM content and burial depth, and critical depth is synthetically controlled by coal rank, formation temperature and fluid pressure. Cirtical depth at equal coal rank becomes shallower as the fluid pressure gradient increasing, while becomes deeper with decreasing of earth temperature gradient at equal coal rank and reservoir pressure gradient. It is also obvious that effect of reservoir pressure on CBM content is stronger than temperature when the burial depth is shallower than "critical depth", while that of temperature is higher than reservoir pressure as the depth deeper than " critical depth".

Experiments of fluid-solid interaction mechanics under temperature and pressure revealed particularity of mechanics properties and permeability and their geological influence factors. It is found effect of confining pressure on coal mechanics is the most obvious in any rank coal. Effect of fluid pressure on low rank coal mechanics is stronger than that temperature, while that on high rank coal is opposite. Further, prediction models for deep coal mechanics properties were constructed. Negatively exponent relationships are found between permeability and effective stress, elastic modulus, Poisson's ratio, while effect of temperature on permeability depending on coal rank is very complex. Through loading the geology factors via three steps, the prediction model is deduced for deep coalbed permeability by coupling sorption, temperature, geostress and fluid pressure.

"Correction coefficient method" for deep coalbed reservoir pressure prediction is put forward, and ternary prediction indexes and model for reservoiring effects of deep coalbed methane are constructed. Deep coalbed methane reservoiring effect of the eastern Ordos Basin is further analysed, and found three types of advantageous and eighteen less reservoiring combinations are found, and their occurrences in the area are predicted.

Key words: deep coalbed methane; reservoiring effect; controlling factor; mathematical model