



2009 Asia Pacific Coalbed Methane Symposium and 2009 China Coalbed Methane Symposium (Vol.1)
2009亚洲太平洋国际煤层气会议暨2009年全国煤层气学术研讨会论文集

煤层气储层与 开发工程研究进展 上

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Advances on CBM Reservoir and Developing Engineering

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内 容 提 要

本书介绍了亚洲太平洋地区煤层气储层与开发工程研究进展,主要包括:煤层气地质与储层工程、煤层气勘探、钻井、完井、增产改造与排采工程、煤层气地面集输、利用工程、煤层 CO₂ 注入与地质储存工程、煤层气政策、经济、市场与信息技术、煤矿瓦斯赋存、运移、抽采及安全工程。

本书可作为煤层气勘探开发及瓦斯抽采等相关科技人员参考、使用。

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前 言

亚洲太平洋地区煤层气资源十分丰富,也是世界上重要的煤炭生产基地,在合理利用这些资源的同时,相关国家有义务共同担负煤矿甲烷减排的重任。为此,中国矿业大学和澳大利亚昆士兰大学联合有关机构,定期举行亚洲太平洋地区国际煤层气学术会议。2008年9月22日至24日,“2008亚洲太平洋地区煤层气学术会议”在澳大利亚昆士兰州布里斯班市成功举行。举办者和与会者同意,乘中国矿业大学百年校庆东风,2009年9月在中国举行“2009亚洲太平洋地区煤层气学术会议”。经与中国石油学会石油地质专业委员会和中国煤炭学会煤层气专业委员会商定,“2009年亚洲太平洋地区煤层气学术会议”与原由中国石油学会石油地质专业委员会和中国煤炭学会煤层气专业委员会承办的“2009年全国煤层气学术研讨会”合并召开。

中国煤层气资源勘探开发近年来取得了快速的发展。截止2009年5月底,全国共钻煤层气井2 818口,包括参数井540口,水平井65口,开发井2 213口,其中1 419口投入生产或正在排采;探明煤层气储量 $1\,790\times 10^8\text{ m}^3$,占总资源量的0.5%。目前,地面煤层气井产能已达每年 $15\times 10^8\text{ m}^3$ 左右,2008年煤层气地面井产量约 $7.5\times 10^8\text{ m}^3$;全国共建有压缩气(CNG)站7座,总设计生产能力130万 m^3/d ;煤层气汽车加气站7座,日加气能力20万 m^3 ;煤层气液化气(LNG)站3座,总设计用气规模155万 m^3/d ;已建成长输管道2条,总长100 km,总设计年输气能力20亿 m^3 ;正在施工建设的长输管道2条,总长140 km,总设计年输气能力50亿 m^3 。煤层气用户主要分布在产气区及周边地区,用途主要有发电、城市居民生活、煤层气汽车(油气双燃料)、小型工业企业用气等。此外,2008年,中国煤矿抽采瓦斯58亿 m^3 ,利用量达20亿 m^3 ;民用已达90万户,发电总装机容量92万kW,世界上规模最大的12万kW瓦斯发电厂已在晋城煤业集团建成发电。

本次会议得到了国内外同行和有关机构的高度关注。本论文集收录论文117篇,其中英文65篇,中文(带英文摘要)52篇,作者来自中国、澳大利亚、美国、日本、德国、荷兰、印度尼西亚7个国家的高等学校、研究机构和企业单位。其中:涉及煤层气地质与储层工程论文57篇;煤层气勘探、钻井、完井、增产改造与排采工程论文29篇;煤层气地面集输、利用工程论文7篇;煤层 CO_2 注入与地质储存工程论文9篇;煤层气政策、经济、市场与信息技术论文7篇;煤矿瓦斯赋存、运移、抽采及安全工程论文7篇。

本论文集分上、下两卷出版。上卷收录了关于煤层气地质与储层工程的57篇论文(包括37篇英文),下卷收录了本次会议其他五个主题的60篇论文(包括28篇英文)。

论文集涉及的论文数量多,内容广,编审时间短,没有时间与作者逐一校核,不足之处在所难免,恳请广大作者与读者谅解。

最后,衷心感谢资助单位、论文作者/全体与会代表及相关的煤层气企业家对本次会议的帮助与支持!

主编谨识

2009年8月31日

Preface

The Asia and Pacific region, where there is one of an important production coal base in the world, is very abundant in coalbed methane (CBM) resources. The countries in the region are bound in decreasing together emissions of coal mine methane (CMM) to atmosphere. To promote the technical exchange and regional collaboration in the CBM/CMM development and utilization, China University of Mining & Technology (CUMT) and the University of Queensland (UQ), Australia, jointed with relative organizations have initiated to convene periodically the Asia & Pacific CBM Symposium. The "2008 Asia & Pacific CBM Symposium" (2008 APCBM) was successfully held in Brisbane, Australia, on 22-24 September, 2008. The hosting institutes and delegates agreed that the 2009 Asia & Pacific CBM Symposium (2009 APCBM) is held in China in connection with the 100th anniversary activities of CUMT. The China CBM Symposium (CCBM) is usually hosted jointly by Coalbed Methane Specialized Committee, China Coal Society (CCS) and Oil Geology Specialized Committee, Chinese Petroleum Society (CPS) for every year. After a satisfying negotiation, it was decided to host a joint 2009 APCBM/2009 CCBM symposium co-organized by CUMT, UQ, CCS and CPS in Xuzhou, China on 24-26 September, 2009.

CBM exploration and development of China have achieved a rapid progress in recent years. Until May of 2009, there were 2 818 CBM wells drilled in China, including 540 parameter wells, 65 horizontal wells and 2 213 production wells. Currently 1 419 production wells are commercially operating. Confirmed CBM reserve in China is about $1\,790 \times 10^8 \text{ m}^3$, accounting for 0.5% of the total CBM resource of China. In 2008, the CBM production was approximately $7.5 \times 10^8 \text{ m}^3$. At present, the CBM producing capacity with surface well has reached about $15 \times 10^8 \text{ m}^3$ per year. Seven CBM compression stations with compressed capability of $1.3 \times 10^6 \text{ m}^3/\text{d}$ and seven CBM filling stations with gas-filling capacity of $200\,000 \text{ m}^3$ have been constructed, and three liquefied CBM plants with design capacity of $1.55 \times 10^6 \text{ m}^3/\text{d}$ have put into production. In addition, two CBM-send-out pipelines with total length of 100 km are operating, with CBM transportation capacity of $20 \times 10^8 \text{ m}^3$ per year. Another two pipelines are building, with total length of 140 km and CBM transportation capacity of $50 \times 10^8 \text{ m}^3$ per year.

Consumers of CBM are mainly distributed in gas production and neighboring areas. CBM is mainly used as the electric power generation, gas supply for urban residents, CBM vehicles (gas and oil bi-used vehicle), small-scale industrial enterprises and so on. Also, the coal mine methane (CMM) of $58 \times 10^8 \text{ m}^3$ were extracted from underground mines of China in 2008, of which about $20 \times 10^8 \text{ m}^3$ were utilized. Now, consumers from urban residents have reached 900 000 families, and the installed gross capacity of the CBM power plants is 920 000 kW. A CBM power plant with the power generation capacity of 120 000 kW, a largest CBM power plant in the world, had been completely constructed and began to generate electricity in Jincheng Coal Group in 2009.

CBM experts, scholars and organizations from China and other countries pay close attention to the symposium. More than 180 authors responded to the Call for Abstracts, addressing the key themes of CBM/CMM and CO_2 -ECBM geosequestration. Total of 117 papers, including 65 papers in English and the others in Chinese with English abstracts, were collected in the publication. Authors in the papers come respectively from China, Australia, America, Japan, Germany, Netherlands and Indonesia.

Thereinto, 57 papers are focused on CBM geology and reservoir engineering, 29 papers on CBM exploration, drilling, well completion and reservoir enhance and recovery engineering, 8 papers on the CBM ground collection, transportation and utilization engineering, 9 papers on CO₂ coal seam sequestration (CO₂-ECBM) and geological storage, 7 papers on CBM policy, economics, marketing and information technology, and 7 papers on CMM occurrence, migration, extraction and safety engineering.

The publication was printed in two volumes, in which the papers on CBM geology and reservoir engineering are arranged in Volume I and those on other five subjects of the symposium in Volume II.

We wish to extend our sincere gratitude to the National Natural Science Foundation of China and other sponsors for the financial support. We are very grateful to all authors, all attendee and other CBM enterprisers for their help and support to this symposium.

Chief-Editors
August 31, 2009

目 录(Content)

第一编 地质与储层工程 (CBM geology and reservoir engineering)

Geological controls on the formation of coalbed methane reservoirs and prediction of target areas of Turpan-Hami basin, Northwest China	Y. D. Cai, D. M. Liu, Y. B. Yao et al. (3)
Preliminary discussion and application of P-wave technique for predicting the gas-bearing property in CBM reservoir	S. L. Chang, Y. Liu, G. F. Li et al. (16)
Swelling behaviors of Yangquan coal induced by adsorption of CH ₄ and CO ₂	G. Q. Chen, J. L. Yang, Z. H. Liu et al. (27)
Characterization of carbonaceous materials for their accessibility to methane—a concept of accessible pore size distribution	D. D. Do, L. Herrera, A. D. Nicholson et al. (29)
Evaluation of the adsorption potentials of argon and methane on the adsorption behavior on carbon surfaces	C. Y. Fan, M. A. Razak, D. D. Do (38)
Adsorption-desorption characteristics for China coal of various ranks	X. H. Fu, J. Y. Wang, B. Quan et al. (47)
Study of the coal ultrafine fractures based on atomic force microscope(AFM)	H. Y. Guo, X. B. Su, X. M. Ni (58)
Coal-bed methane potential of Qinshui basin, Shanxi, China	X. M. Huang, G. L. Jia, Y. F. Wang et al. (63)
The permeability picture: a coalbed methane collage	Ian Palmer (68)
The optimization of evaluation index on high abundant CBM enrichment area	X. L. Jin, J. W. Li, Z. Y. Yang (82)
Gas sorption and transport processes in coals:Recent results of an Australia-China-Germany research co-operation	B. M. Kross, Y. Gensterblum, F. Han et al. (86)
A study on the relationship between anthracite fissure-pore system and the production of coalbed methane in Jincheng	G. H. Li (94)
Really CO ₂ dissolvable into coal structure, fiction or fact	H. Y. Li, S. Shimada, N. Sakimoto (100)
Study on methodology of small scale coalbed methane exploitation target block evaluation	L. C. Li, C. T. Wei, X. H. Fu et al. (107)
The response of porosity properties of low-grade coal reservoirs to Magma invasive	W. Li, Y. M. Zhu, H. Wang et al. (114)
Geologic control on CBM content in a certain developing block of southern Qinshui basin	H. H. Liu, S. X. Sang, Y. M. Li et al. (119)
Analysis of reservoir characteristics and main geological control factors of CBM in Pingdingshan coal mining area	Z. Ou, F. C. Wu (125)
Prediction of coal porosity using seismic and logging data	J. Qian, R. F. Cui, T. J. Chen (131)
Geology and potential of Coalbed methane resources from Guizhou, China	

- Y. Qin, D. Gao, C. T. Wei et al. (137)
- Long term permeation and diffusion of gas in coal reservoirs A. Saghafi (144)
- Analysis of solid-liquid-gas interaction in coal reservoirs based on Dubinin-Radushkevich model
..... S. X. Sang, S. Y. Zhang (150)
- The discussions between structure curvature and coalbed methane production parameters of Zaoyuan
block of Qinshui Basin J. Shen, Y. Qin, X. H. Fu et al. (156)
- The impact of components concentration on CH_4 desorption in CO_2 - CH_4 mixed gas desorption isotherm
experiments S. H. Tang, C. X. Ma, S. H. Zhang et al. (162)
- Experimental study on directional permeability of coal for coalbed methane recovery
..... G. X. Wang, P. Massarotto, V. Rudolph et al. (170)
- Study on enrichment area of coalbed methane in the middle part of Hedong coal mine field
..... J. L. Wang, X. H. Fu, J. Y. Wang et al. (180)
- Study on tectonic stress field in the middle part of Hedong coal mine field
..... J. Y. Wang, X. H. Fu, J. L. Wang et al. (187)
- A study in adsorption characteristics of lignite in China K. X. Wang, X. H. Fu, A. H. Liu (195)
- Study on model of drainage induces permeability change and reservoir modeling in coalbed methane
vertical well C. T. Wei, Y. Qin, X. H. Fu et al. (201)
- Experimental study of anisotropic strain behavior of Coal
..... X. R. Wei, P. Massarotto, V. Rudolph V et al. (208)
- Study of CBM geology characteristics of Gemudi syncline in the west of Guizhou Province
..... C. F. Wu, Q. Feng, J. F. Zhang et al. (218)
- Characteristics and controlling factors of the coal reservoir pressure of Panguan syncline in western
Guizhou Province H. Xu, D. Z. Tang, S. H. Tang et al. (224)
- Study on the seepage law of coal-rock fragments in goaf Q. Xu, S. Q. Yang, B. H. Yu et al. (229)
- Investigation of the preferential adsorption/desorption behavior of N_2 , CH_4 and CO_2 on coal
..... Y. B. Yao, D. M. Liu, Y. W. Gao (239)
- Exploration orientation and development proposal of coalbed methane in Qinshui basin of Shanxi
Province J. P. Ye, X. M. Peng, X. P. Zhang (248)
- Fractal characteristics of coal reservoir micropore system, east margin of Ordos basin
..... S. H. Zhang, S. H. Tang, D. Z. Tang et al. (256)
- The theoretical model for porosity evolution during coal deformation process
..... J. Zhu, Y. D. Jiang, Y. X. Zhao et al. (266)
- Dynamic 4D coal permeability—the benefits of a constant volume reservoir
..... P. Massarotto, D. G. Suzanne, V. Rudolph (271)
- 羊叉滩井田地下水与煤层气赋存运移的关系 曹新款, 朱炎铭, 赵雯等 (287)
- 贵州格目底向斜煤层气成藏地质特征及勘探潜力 陈贞龙, 王峰, 汤达祯等 (292)
- 沁水盆地南部煤层气单井产量影响因素分析 陈振宏, 王一兵, 杨焦生等 (298)
- 鄂尔多斯盆地深部煤层气勘探潜力分析 董昭雄, 康毅力, 何国贤等 (305)
- 煤体变形对煤晶体结构的影响 郭盛强, 苏现波 (311)
- 沁水盆地郑庄区块影响煤层气产能的因素浅析 胡向志, 齐治虎, 张振伦 (316)
- 华北晚古生代含煤盆地构造演化过程中煤层气赋存特征与富集机理
..... 琚宜文, 侯泉林, 范俊佳等 (321)
- 煤层气储层物性变化规律研究 康永尚, 尹锦涛, 邓泽等 (330)
- 煤层气非均质分布特征及富集规律探讨 李辛子, 顿保亮, 关达等 (338)
- 焦作恩村井田二₁煤层含气量控制因素分析 苗永亮, 张振伦, 胡向志 (349)

鄂尔多斯盆地大宁—吉县地区沉积作用控气特征分析	牛海青,陈世悦,韩小锋 (353)
青山矿区水文地质控气特征研究	彭伦,傅雪海,刘龙乾等 (363)
二元气体的等温吸附—解吸实验分析	王杰,吉雨,李森等 (368)
川南煤田古叙矿区大村矿段煤层气储层特征及改造的探讨	尹中山 (373)
高煤级煤储层条件下的气体扩散机制	张小东,刘炎昊,桑树勋等 (378)
万全煤田褐煤煤层含气量的确定	赵本肖,傅雪海,李英超等 (386)
初论煤储层的非均质性	赵万福,马永明,李新民等 (396)
高丰度煤层气富集区之我见	周宝艳,傅雪海,孙文卿等 (402)
煤层气储层数值模拟技术研究综述	张先敏,周登科 (405)

第二编 钻井、完井、增产改造与排采工程 (CBM exploration, drilling, completion and reservoir enhance and recovery engineering)

Successful strategies for dewatering wells using ESP's	L. Bassett (421)
Microbially enhanced coalbed methane production in laboratory	R. Chen, Y. Qin, Z. B. Yang et al. (427)
Detecting of coal bed fractures using P-wave data	T. J. Chen, R. F. Cui, X. Wang et al. (432)
Research on the level of stable production in the development of coalbed methane well	Y. D. Guo, Y. J. Zhao, Z. P. Li (439)
Principle of well-net design for coalbed methane exploitation in coal mining area	B. S. Han, J. J. Wang (448)
Influence of mining and strata structure on relieved coalbed methane drainage by surface vertical well	H. Z. Huang, S. X. Sang, L. C. Fang et al. (457)
New mathematical model for increasing the production of coalbed methane	L. Jin, G. Jin (465)
Study of adaptive improvement on the electrical submersible pump in CBM cluster wells	B. Y. Wang, H. Deng, Z. Y. Zhao et al. (469)
Study of main factors having impact on fracturing results of coal seams and appropriate countermeasures	X. Wang, Y. H. Ding, Y. Xu (474)
Advance of the application of well logging to coalbed methane exploration	J. F. Yu, K. Guo, X. X. Yuan et al. (486)
Research and application on testing technology of orientation by potentiometry method for coalbed fracturing	J. C. Zhang, X. Zhang, A. G. Wang et al. (495)
Study on coalbed methane development with low cost drilling and stimulation technologies	Y. Zhang, B. A. Xian, F. J. Sun et al. (503)
Application of the coalbed methane cluster well technology and existing problems in Jincheng mining area	Z. Y. Zhao, B. Y. Wang, Y. D. Tian et al. (515)
Features of CBM (coalbed methane) exploration and development in China	J. M. Li, H. Y. Chao, G. H. Wen et al. (519)
煤层气羽状水平井井眼轨迹控制技术研究	鲍清英,鲜保安,张义等 (526)
雪姆 T130 车载钻机在沁水盆地煤层气井施工中的应用	曹可义 (533)
煤层气多分支水平井井位优选及井身结构优化研究	陈艳鹏,王一兵,杨焦生等 (536)
沁水盆地煤层气压裂技术研究	金显鹏,兰乘宇,周红艳等 (543)
煤层水力压裂裂缝诊断方法与评估分析	李安启,辛洪波,杨焦生 (549)

大宁—吉县地区煤层压裂技术分析	马财林, 权海奇, 王前平等 (554)
大宁—吉县地区煤层气井生产特征研究	权海奇, 王前平, 马财林等 (563)
AVO 技术在煤层气富集区预测中的应用	孙斌, 孙粉锦, 杨敏芳 (568)
从 151-气 1 井探索新疆地区低阶煤的高效完井工艺技术	孟福印, 王德桂, 徐凤银 (574)
地震勘探还能给煤层气勘探开发做什么?	王赞, 芦俊, 尹军杰 (579)
煤层气地震勘探关键技术问题浅析	尹军杰, 邢春颖 (584)
转换波共散射点道集成像方法	尹军杰, 王赞, 王伟等 (590)
中国煤层气分布特征、开采特点与勘探适用技术	赵庆波, 陈刚, 李贵中 (599)
煤层气地面立体排采技术	赵万福, 雷华友, 李新民等 (609)
煤层压裂实时评估技术在韩城区块的应用	李署光, 郭大立, 计勇 (614)

第三编 地面集输、利用工程 (CBM ground collection, transportation and utilization engineering)

Research on management of coalbed methane warehousing and transportation based on GIS	Y. F. Li, M. H. Zhang, Y. J. Wang et al. (623)
Driving mechanism of porous burner to Stirling engine powered by coalbed methane	B. S. Zhang, N. Chen, Z. C. Song (631)
Study on the calculation of calorific value of coalbed gas in Jincheng region in Shanxi province	B. Wang, G. Z. Li, F. J. Sun (636)
煤层气田地面集输数据采集及自动控制技术现状分析	陈仕林 (642)
利用燃气发动机直接驱动的煤矿主斜井皮带输送机	樊铁山, 王保平, 李志奇 (646)
油气管道安全性检测的技术分析与技术整合	刘羽飞, 殷蔚明, 张立欣等 (650)
沁水盆地煤层气樊庄区块采气管网建设的应用与优化	许茜, 王登海, 王红霞等 (654)
中国煤层气(煤矿瓦斯)开发利用现状及潜力研究	黄盛初, 刘文革, 韩甲业 (658)

第四编 煤层 CO₂ 注入与地质储存工程 (CO₂ sequestration into coal seam (CO₂-ECBM) and geological storage engineering)

In-situ numerical testing of CO ₂ sequestration in coal; impact of residual water	D. Chen, J. S. Liu, J. G. Wang et al. (669)
In-situ numerical testing of CO ₂ sequestration in coal; effects of confining stress and injection pressure	Z. W. Chen, J. S. Liu, E. Derek et al. (677)
CO ₂ storage mechanism in coal and its effect on methane production in enhanced coalbed methane recovery	S. Shimada, N. Sakimoto, Z. J. Chai (686)
In-situ numerical testing of CO ₂ sequestration in coal; dual poroelastic effects	Y. Wu, J. S. Liu, Z. W. Chen et al. (695)
Gas adsorption measurement on coals for CO ₂ -ECBM	J. S. Bae, S. K. Bhatia, P. Massarotto et al. (704)
Implications of natural analogue studies for CO ₂ storage in coal measures with enhanced coal bed methane	S. D. Golding, I. T. Uysal, C. J. Boreham et al. (712)
煤层二氧化碳注入与地质存储研究进展评述	王国玲, 秦勇, 邵波等 (726)

沁水煤田 CO ₂ 置换煤层气实验与注气增产方案的研究	赵威, 坛俊颖, 谈红梅等 (733)
温室气体 CO ₂ 的地质处置研究评述	赵雯, 朱炎铭, 陈尚斌等 (738)

第五编 政策、经济、市场与信息技术 (CBM policy, economics, market and information technology)

The research of coalbed methane economic assessment method involved in uncertainty parameters	Y. H. Chen, Y. G. Yang, Y. Qin (745)
Study on the information management system about CBM exploration and development by GIS	J. X. Song, X. B. Su, L. Y. Wang (752)
Review on comprehensive utilization and developmental strategy of seam gas in low-carbon economy perspective	D. Q. Sun, Y. Fan, T. Zhang et al. (759)
世行贷款在山西沁水盆地煤层气田开发中的应用	薛岗, 王红霞, 许茜等 (764)
中国煤层气资源开发与市场发展浅谈	张政和 (768)
三维可视化概念层次模型在煤层气指标体系的应用	都平平, 李文平, 王林秀等 (773)
浅析中国煤层气开发政策和法律	李昕 (778)

第六编 煤矿瓦斯赋存、运移、抽采及安全工程 (CMM occurrence, migration, extraction and safety engineering)

Study on mine of safety evaluation based on unascertained measure model	Z. Y. Chen, G. Z. Zhang, C. F. Wu et al. (787)
Potential hazard of coalbed methane accumulation in quarterly sandstone aquifer in Barito Kuala District, Indonesia	D. Triwibowo (793)
朱仙庄煤矿瓦斯赋存的构造控制机理	窦新钊, 姜波, 汪吉林等 (801)
贵州莆河—山岔河矿构造煤类型及其孔隙结构	李明, 冀铭君, 姜波等 (807)
常村矿井下钻孔孔壁瓦斯涌出数值模拟	四旭飞, 张文平, 杜春志 (813)
太原西山矿区煤层瓦斯赋存特征	解奕炜, 吕福祥, 李文生 (818)
阳泉矿区 3 号煤层瓦斯地质特征和煤与瓦斯预测	王一, 张会青, 刘培宏 (823)

第一编

地质与储层工程

Geological controls on the formation of coalbed methane reservoirs and prediction of target areas of Turpan-Hami basin, Northwest China

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【Abstract】 To better understand the controls on coalbed methane (CBM), a lot of surveys and experiments (including coal petrology analysis, mercury porosimetry, Brunauer-Emmett-Teller (BET) nitrogen adsorption at low temperature and methane adsorption/desorption) are conducted. The structures, coal-bearing strata and coal facies are revealed by geological research and the laboratory tests showed the coal petrologic characteristics, coal types, macerals, vitrinite reflectance (R_o), permeability, pore and cleats characteristics and coal adsorption/desorption ability. Finally, based on above analysis, analytic multi-hierarchy process-fuzzy mathematics (AMP-FM) method is introduced into appraising the CBM resources. The results show that Turpan-Hami basin was divided into five levels for CBM resources, in which Aiwei ergou and Yilahu mines are the most favorable CBM development districts. Total CBM resources less than 1 500 m in Turpan-Hami basin are $2.0587 \times 10^{12} \text{ m}^3$ calculated using cubage method, and the average abundance of CBM resources for Turpan-Hami basin is $1.56 \times 10^8 \text{ m}^3/\text{km}^2$.

【Key words】 geological controls; coalbed methane reservoir; prediction; Turpan-Hami basin

1 Introduction

Coalbed methane (CBM) resources are very abundant in the Turpan-Hami Basin, which is the basin with low rank coal. Although many CBM exploration and basic research projects have been initiated, nowadays most are concentrated on limited districts of the basin (Yang et al., 1996; Li et al., 2003; Yang et al., 2005). Only some preliminary studies on reservoirs and gas content (Hu et al., 2002; Li, 2002; Ning et al., 2003; Liu et al., 2006; Yang, Li, 2008) have been conducted in the Aiwei ergou and Shaerhu coalfields in the Turpan-Hami Basin.

Some studies related to the geological features of the basin and some primary evaluation of CBM reservoirs (including the Aiwei ergou and Hami Coalfields) have been conducted (Hu et al., 2003; Yang et al., 2005), but these data are insufficient for evaluating the CBM potential and determining the target area. In this paper, we will report the data from the field and laboratory study on the geological controls of CBM, and the reservoirs, the resources and the production potential. With the available data and analytic multi-hierarchy process-fuzzy mathematic (AMP-FM) model (Sun et al., 2000; Yang 2000; Yao et al., 2008; Liu et al., 2008), we attempt to generalize the most favorable conditions for CBM production and to predict the target areas with good CBM production potential.

2 Geological setting

2.1 Tectonic settings

Main structural lines of coal-bearing strata in Turpan-Hami basin are NE-NW-NE-NW from west to

east, which performs as "W". NE structural line developed from western Tuokexun and Taibei sub-depressions to eastern Liaodun uplift, NW structural line developed in Aidinghu slope, western Taibei and Hami sub-depressions. This "W" type structural line is controlled by base background and surrounded with mountains. Kalawucheng, Bogeda and Haerlike mountains form the north boundary of the basin. The formation of main structural lines was controlled by the activity of these mountains at different stages and scales (Zhao et al., 1992; Tong, 1999; Lu, 2001; Zhang, 2000; Tang et al., 2003; Dai et al., 2005; Zhou, Yao, 2006). At the Indonesian movement stage, a series of NW structures are created by the activity of mountain Haerlike. At the Yanshanian movement stage, a series of NE structures are formed by the activity of mountain Kalawuchen due to two structures interspersed each other. At last, the netlike structures performed in the basin at the Yanshanian stage. At the Himalaya movement stage, the uplift of mountain Bogda resulted in nearly N-S compressive stress. The original lines are composited, adjusted, which due to a number of recent east-west extensional structures and near-vertical N-S faults formed. By the multi-phase structural changes, the north-south zonation is the basic characteristics of Turpan-Hami basin, which (mainly the northern part of the Turpan Depression zone) appeared with the distribution of different structural features.

Turpan-Hami basin is made up of composite sedimentary basins formed at different periods. The basin exists among the confluence spot of three major plates of the Northwest China, and the boundary of the basin is very complex. Based on structural characteristics of different structural stratum, Zhang et al. (1997) recognized that the tectonic stress of the basin at early Permian is NE-SW stretch region stress field, and at the late Permian is S-N extrusion region stress field, while at the Indonesian stage it's NW-SE extrusion dextrorotation sub-class stress field, at the Yanshanian stage it's NE-SW extrusion stress field which levorotation sub-class stress field derived from, and at the Himalayan stage NE-SW extrusion stress field (Ji, Qin, 2005).

2.2 Coal-bearing strata

The clastic rocks deposited in fluvial, lacustrine and swamp facies in the Turpan-Hami Basin, in which Jurassic coal-bearing strata mainly occur. The total thickness of the strata is close to 4 000 m, which are divided into the Lower Jurassic Badaowan and Sangonghe Formations, Middle Jurassic Xishanyao, Sanjianfang and Qiketai Formations, and Upper Jurassic Qigu and Kalazha Formations. Coal seams mainly occurred in the Lower Jurassic Badaowan and middle Jurassic Xishanyao Formations.

3 Experimentals

Vitrinite reflectance (R_o) and coal lithotype tests are conducted on microscope photometer (MPV-III, Leitz) following the GB/T 6948—1998. standard procedure at laboratory of coal geology, China University of Mining and Technology in Beijing, average vitrinite reflectance ($R_{o,max}$) (immersion in oil) is acquired. Coal macerals are counted by the scheme of International Committee of Coal and Organic Petrology (ICCP, 1998).

Mercury porosimetry parameters (pressure, pore diameter and mercury volume) are automatically recorded by Autopore 9410 analyzer (micrometrics, US) following SY/T 5346—1994 (Chinese Oil and Gas Industry) and permeability parameters are acquired following the SY/T 5336—1996. At the same time, the tests of specific surface area, pore diameter and isothermal adsorption/desorption experiments are conducted at the Gas Research Center, Langfang Branch of Research Institute of Petroleum Exploration and Development, China National Petroleum Corporation. The isothermal equipment conditions are as follows: high-pressure CH_4 gas, the purity 0.999, and the initial pressure 14 MPa, average experimental temperature of 35 °C (Calculated from Turpan-Hami Basin geothermal gradient) in depth of 1 000 m of Turpan-Hami basin, and the water equilibrium method for testing.

4 Results and discussions

4.1 Potential of CBM generation

4.1.1 Coal facies

The Jurassic coal seams of Turpan-Hami basin mainly developed in dry peat swamp, forest peat swamp, peat swamp with flowing water and fresh water marsh facies. During the Badaowan period, the forest peat swamp facies developed in Tuokexun-Turpan, while in Sandaoling, Aiweiergou and near the well Hacan 2 dry peat swamp developed. Dry peat swamp and forest peat swamp developed extensively with the obviously eastward shift, fresh water peat swamp and fresh water marsh developed with local distribution during the Xishanyao period. From the plane distribution of coal facies, the thick coal seam occurs stably in the forest peat swamp zone, in which large amount of CBM generated. The properties of coal reservoirs are also well-developed, which is favorable for CBM accumulation.

4.1.2 Coal petrography

The generation and concentration of CBM during coalification are revealed by the controls on the adsorption capacity and reservoir properties. High coal ranks in the Yemaquan and Aiweiergou mining areas are related with magma intrusion resulted from the activity of Boluokenu-Aqikekuduke deep fault (Yang et al., 1996). According to former studies (Yang et al., 2000), the results showed that magmatic metamorphism of coals can improve the porosity and permeability and promote CBM production, which is beneficial to CBM exploration and development.

Coal petrology of Turpan-Hami basin is very special and characteristics of coal macrostructures are different as well. The bright coal for Aiweiergou and Kekeya coal mines are very thick, the structures of conchoids and eyeball-like are very obvious (Figure 1). Fusain occurs more frequently, single-layer is normally thick, the thickness of fusain-rich coal can be as large as 2 m, such as No. 4 coal seam in Sandaoling (Figure 2). The characteristics of sapropel coal show that it is pure and light, and characterized with conchoidal fracture, homogeneous structure and massive structure. The thickness is always larger than 0.5 m, as in the Kekeya coal mine (Figure 1). As for a small number of coals, the macrolithotypes vary from bright to semi-bright. Microlithotypes of Turpan-Hami basin for Jurassic coal are characterized by more durite and less vitrite. While in the Aiweiergou coal mine, vitrite is the major coal microlithotype.

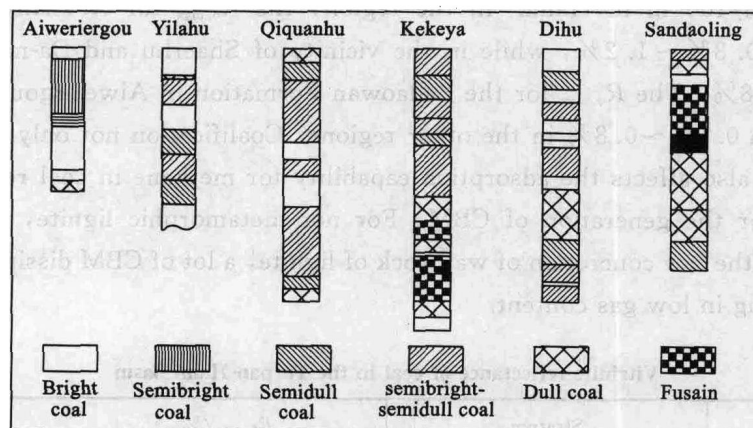


Figure 1 Lithotypes of main coal seams in Turpan-Hami basin

Vitrinite gives its priority to coal macerals of Xishanyao and Badaowan Formations in Turpan-Hami Basin, which up to 40%~95%. Inertinite contents vary from 2% to 67%, with an average of 20%. Liptinite content is less than 10%. According to the thermal simulation experiments (Zhao et al.,

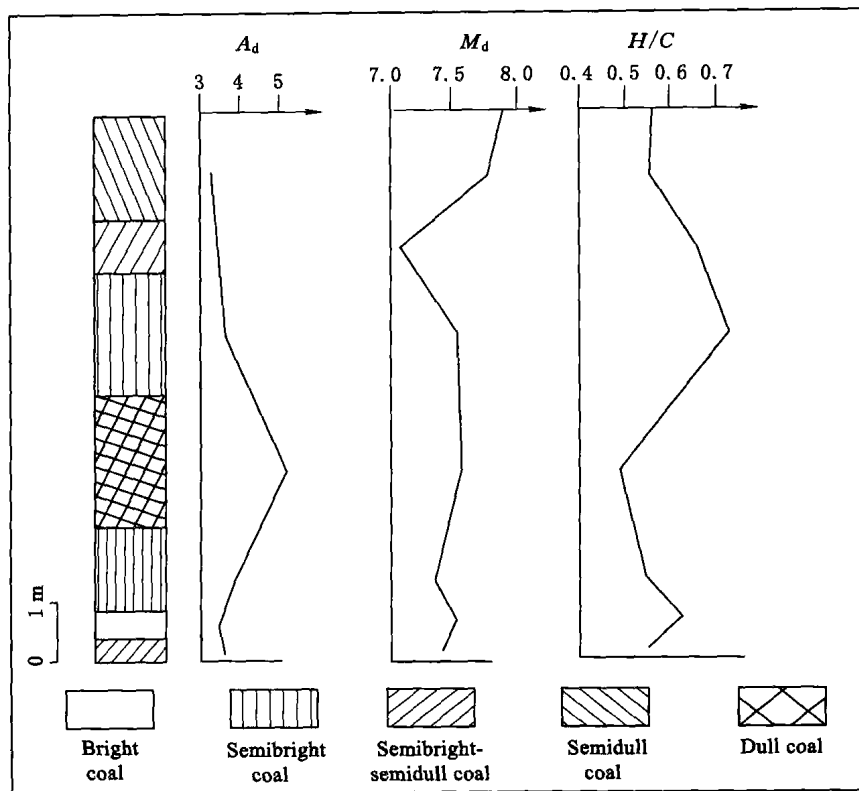


Figure 2 Coal petrological and coal quality of No. 4 coal seam in the Sandaoling coal mine

1997), the liptinite is the most favorable type for CBM production, followed by vitrinite and inertinite. The total gas production is different due to the different content of macerals.

Coal types in the Turpan-Hami Basin are very complete, which ranges from lignite to the lean coal, while kennel coal and non-caking or weakly caking coals are the main types.

4.1.3 Coal rank

Coal vitrinite reflectance for Turpan-Hami Basin largely changes from 0.38% to 1.9% (Table 1). In general, $R_{o, \max}$ values increase from 0.38% to 1.2% with increasing the depth of coal seam (Figure 3). In the Taipei district, the vitrinite reflectivity gradient is 0.035%/100 m, 0.22%/100 m in Tuokexun and 0.05%/100 m in Hami. In the region, the $R_{o, \max}$ for Xi-shanyao seam around the Wutongwozi is up to 0.8%~1.2%, while in the vicinity of Shaerhu and Da-nanhu mines it is at a minimum of about 0.38%. The $R_{o, \max}$ for the Badaowan Formation in Aiweiergou is up to 1.9% more than that ranging from 0.5%~0.8% in the other regions. Coalification not only influences on the gas generation of coal but also affects the adsorption capability for methane in coal reservoirs. Lower coal rank is unfavorable for the generation of CBM. For non-metamorphic lignite, only biochemical gas generated. Because of the low concretion of wall rock of lignite, a lot of CBM dissipates from the coal reservoir, which resulting in low gas content.

Table 1 Vitrinite reflectance of coal in the Turpan-Hami basin

Sampling spot	Stratum	$R_{o, \max} / \%$	Coal rank
Hami	J ₂ x	0.38~0.58	Lignite-Kennel coal
Sandaoling	J ₂ x	0.52	Kennel coal
Hacan 1	J ₂ x	0.57	Kennel coal
Well Fang 1	J ₂ x	0.6~0.7	Kennel coal