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Distribution Characteristics of Shallow Natural Gas in China Oil Fields and Its Influence on Drilling

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As shallow gas reservoir was widely distributed in oilfield of China, it was defined as all kinds of gas with buried depth less than 1500m. The methane component content was 45%~97.28%; and methane carbon isotope value $\delta^{13}\text{C}_1$ varied from 38.0‰ to 67.90‰, namely, based on the characteristics of carbon isotope and gas components in this field, it was believed that the thermogenic natural gas and microbiogenic gas were existed, though the shallow natural gas can be gathered into reservoir and has the industrial exploitation value. For the shallow buried of the shallow natural gas and the formation lithology with low diagenesis and high pressure, some phenomenon was often occurred such as well kick, gas leakage at well head, gas streaming, mud gas invasion, or blowout in severe case while drilling. The gas blowout accident and personal safety occurs frequently. The identification and evaluation of shallow natural gas reservoir can be means of drilling, total hydrocarbon gas logging and log interpretation. It can provide the reliable evidence for identification and evaluation of natural gas and promote the exploration and development process of shallow natural gas.

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Keywords: Shallow gas; methane gas; natural gas reservoir; blowout; drilling

Introduction

The shallow gas was defined as all kinds of gas with buried depth less than 1500m^[1-3]. It can be methane gas of bacteriogenic effect formed by sedimentary organic matter of biodegradation; it may be

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associated gas formed by thermal degradation of organic materials; it may be the gas migrated from the deep layer and then accumulated together, which formed by thermal degradation of organic materials and it may be the alkane gas owing to polymerization of molecules containing carbon (CO, CO₂, CH₄ and so on)^[4]. The shallow gas was common existed in oilfield of China; some of the shallow gas reservoir has the industrial exploitation value^[1, 2, 5, 6]. The security threats exists in the engineering during the drilling process of the shallow gas, the gas blowout accident and personal safety accident occurs frequently due to the influence of shallow gas during the drilling process. High attentions had been paid on the exploration of shallow gas for the oilfield in recent years, whether from aspect of reservoir formation or drilling disasters.

1. Distribution characters of shallow gas

In Daqing oilfield, the north of Song-Liao basin Shallow gas generally developed on upper cretaceous Mingshui formation the second, the third and forth section of lower cretaceous NunJiang formation and the buried depth was about 200~400m. The distribution condition of shallow gas was shown in table.1.

The shallow gas was also developed in Jilin oilfield, the south of Song-Liao basin, mainly distributed on upper cretaceous Sifang formation and the buried depth was about 100~600m, it can be reached 80m of buried depth in some individual oilfield such as: Songnan 30#well, 24# well and 301# well. There were more than ten gas-bearing layers in drilling formation^[1, 7]. The shallow gas was wide distributed on Langfang, Bazhou and Wen'an of Huabei oilfield and the buried depth was about 650~800m (Minghuazhen formation) and 1100~1500m (Guantao formation)^[8]. The buried depth of gas reservoir was about 300~900m (Minghuazhen formation) and 800~1400m(Guantao formation) in Gudong and Gudao oilfield formation of Shengli oilfield in Shandong, such as the buried depth was 1169m, 225m and 321.1m for gudao GD7 well, B24#well and B24-1# well respectively. In Liaohe QD oilfield, the shallow gas was distinguished in Qiandangpu, Damintun and Xinglong formation, for instance, the buried depth of shallow gas was 1397~1441m for Qianq1 well, Qianq5 well and Qianq7well; it was obviously showed that the gas existed in 1515.0~1512.0m of buried depth for X462 well of Xinglong oilfield^[10]. The shallow gas was distributed on Nm1, Nm2 and Nm3 of Minghuazhen formation, it was Nm2 where the gas bearing area was the largest and the distributed area was most widely. Moreover, the gas bearing area was lesser and the buried depth was about 600~800m^[3]. The shallow gas was distributed generally in Bohaiwan sea oilfield, for instance, 19-3-3# well of Penglai, 25-1-6# well of Bozhong, the gas was rich in 500~800m of buried depth^[11].

Table 1 Shallow natural gas distribution of Daqing oilfield

Oilfield	Reservoir construction	Well	Layer	Depth(m)	Data sources
Daqing Oilfield	Xingshugang	x2-2-24	K1n4	195~240	Author
		x2-3-26	K1n4	216~218	
		x2-3-20	K1n4	270~280	
		X1-3-19	K1n4	310~323.7	
		X242	K1n2	507~537	
		X7-D2-135	K1n2	552	
	Aonanbi	Ao7	K2n1	491.8~496.2	Xu Yunxin 1995
	Longnan	Gu31	K1n3	650.0	
	Putaohua	Puqian7	K1n3	409.6~404.0	

Puqian701	K1n4	276.4~400.0	
Puqian 801	K1n4	318.2~373.8	
Pu10、4、46	K1n3	405.2~403.2	
Puqian 4-geng41	K1n4	255.6~264.5	
Puqian 5-61	K1n4	251.3~260.3	
Puqian 6-geng61	K1n4	264.2~275.2	
Puqian 3-6	K1n4	254.2~261.8	
Puqian 3-geng31	K1n4	284.5~	
Xinbei	Xinbei44	K1n3	405.0~420.0
	Xinbei54,	K1n3	445.2~449.8
Gaotaizi	Gao32、35	K1n2	638.5~641.0
Saertu	Sa155	K1n2	388.0~378.5
	Sa7	K1n2	448.0~442.0

2. Methane content and carbon isotope characteristics of shallow gas in oilfield

There was somewhat difference of shallow gas component among different oilfield and different structural area controlled by the structure and buried depth, of course, there was significant difference for methane content and carbon isotope which indicates the genesis of shallow gas (table2). ^{12}C was rich in bacterial methane (trace amount of heavy hydrocarbons, C_2H_6 , C_3H_8 and C_4H_{10}), $\delta^{13}\text{C}$ was lighter and whose value varies from -60‰ to -55‰; carbon isotope value of thermogenic natural gas was heavy and the value of $\delta^{13}\text{C}$ varied from -50‰ to -35‰.

Daqing oilfield of Songliao basin Putaohua strucuture, methane gas was the main component of the shallow gas and its content reached 73.1%~94.4%; Nose structure in Puxi, low content of methane in shallow gas and its content reached 45.0%~85.72%. The carbon isotope value of $\delta^{13}\text{C}$ varied from 67.9‰ to 60.03‰ and generally lower than -55‰, it had the characteristic of bacterial biogenic gas^[2, 6]. The methane carbon isotope value of $\delta^{13}\text{C}$ was generally lower in most structure of Songliao basin. Such as the $\delta^{13}\text{C}$ value of methane gas varied from 38.0‰~48.83‰ in Xingshugang structure; it indicates that thermogenic natural gas was existed in Saertu, Gaotaizi, Longnan structure and the $\delta^{13}\text{C}$ value of methane gas varied from -49.50‰~52.42‰^[5]. In the same way, the $\delta^{13}\text{C}$ value of methane gas varied from -42.3‰~52.5‰, it showed that the shallow gas was thermogenic natural gas type. Therefore, it means the diversities of shallow gas resource type, it can not only be microbiogenic gas, but also can be thermogenic methane.

Table.2 Methane concentration and isotopes characteristics of Shallow natural gas in oil fields

Oilfield	Reservoir construction	Well	Layer	Depth (m)	CH4(%)	$\delta^{13}\text{C}$ (PDB. ‰)	Data source
Daqing Oilfield	Putaohua	Puqian4-geng41	K1n4	255.6~264.5	65.21	-65.05	Fu Xiaofei 2011
		Puqian 3-6	K1n4	254.2~261.8	85.72	-67.90	
		Puqian 3-geng31	K1n4	284.5	59.92	-62.77	

Xingbei		Puqian 5-61	K1n4	251.3~260.3	45	-61.74	
		Puqian 6-geng61	K1n4	264.2~275.2	63.8	-60.03	
	Xingqian3	Xingqian3	K1n4		97.28	-38.0	Author
		Xingqian 6	K1n4		96.32	-47.7	
		X3-1-613	K1y1		87.26	-48.8	
		X135	K1y1	990.0	82.07	-42.57	
		Sazhong6 22	K1q2-3	970.0	86.21	-52.42	
	Saertu	Bei1 6 39	K1q2-3	1100.0	83.47	-51.11	Xu Yunxin 1995
		Gao30 27	K1n2	1050.0	72.89	-51.21	
	Gaotaizi	Gu38	K1y1	1400.0	68.29	-49.50	
	Longnan						
Dagang Oilfield	Gangxi	Binqian7	Nm	636.5~ 639.8	889.11	-42.3	Wang Zhensheng 2009
		Binqian 7	Nm	712.9~ 719.6	95.82	-52.5	

3. Identification of shallow natural gas in oilfield

3.1. Display of shallow natural gas during drilling process

For the shallow buried of the shallow natural gas and the formation lithology with low diagenesis and relatively loosen rocks, it frequently leads to some phenomenons such as bubbling around wellhead, gas streaming once the shallow natural gas gathered and oppressed. During the drilling process, it was often occurred the phenomenons like well kick, gas leakage at well head, mud gas invasion, or blowout in severe case while drilling. For instance, gas streaming and water inflowing occurred on western spot and spreading to wellhead after finishing drilling of Xing 1-3-27 well. Well kick occurred when drilling to depth of 215m while drilling for Xing 2-3-6 well. When drilling to the depth of 170~180m, a great quantity natural gas, mud, water, rock waster were gushing out to the height 35m in Xing 3-3-22 well . For the Xing1-4-DS21 and Xing1-4-DS 23 well, the mud gas invasion phenomenon occurred when drilling to the upper formation of Nun 2 section.

3.2. Gas logging of total hydrocarbon and logging curve

It can be seen that the curve of total hydrocarbon changes significantly and has the characteristics of quick up fast down, the total hydrocarbon curve shows high peak value 1.8~4.9, the ratio of maximal total hydrocarbon value to base total hydrocarbon exceeds 5 (59~49), the ratio of heavy hydrocarbon to total hydrocarbon was lower; the apparent resistivity value $R_{2.5}$: 8.4~18 $\Omega\cdot m$, the potential amplitude difference was 6~13.5mv.

For instance, the unusual phenomenon appeared at the 559m of depth level, it can be seen from the total hydrocarbon curve of upper formation in Nunjiang 2 section, the ration was 0.75% and 0.1% for total hydrocarbon content and heavy hydrocarbon respectively. During the drilling process, at the depths of 552m, 553m, 556m, the average content of the methane gas was: 98.78%、98.19%、96.56%, respectively, the average content of ethane gas was 1.22%、1.71%、3.44%, it indicates that was relatively pure dry gas. From the logging curve, it was obvious showed that the spontaneous potential was 4mv, apparent resistivity R2.5 was 10 at the depth of 552.4~554m respectively, similarly, the spontaneous potential was 3 mv and the apparent resistivity R2.5 was 14 respectively.

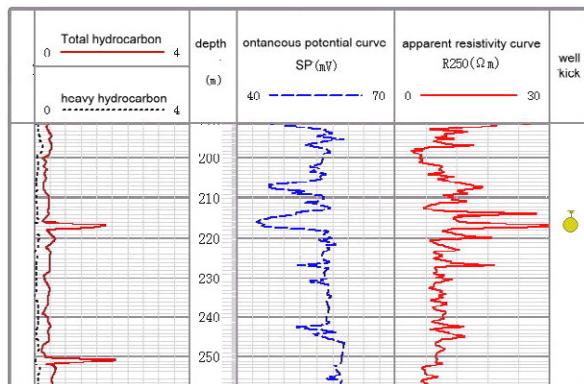


Fig.1 Total hydrocarbon curve, spontaneous potential curve and apparent resistivity curve of shallow natural gas in Xing 2-3-26 well

4. Damage of shallow natural gas on drillings

The shallow natural gas possesses industrial utilization value and it was significant for improving oil recovery. Since its shallow buried depth and the formation lithology with low diagenesis, from aggregation to enrichment of the shallow natural gas, it has brought some problems to drilling on oilfield. In a large number of these wells, vertical migration of gas from unknown sources to the surface via well casings and surrounding soils represents a serious environmental problem. Well kick can be occurred when the shallow natural gas migrating with great speed to the wellhead, once the shallow gas invading into the well hole. A series of damage would be emerged such as fire disaster, collapse of wellhole, drilling tool stuck or wellhole discarding, more seriously, it can lead to surface collapsed, drilling rig being buried, it would also can lead to destroyed and polluted of the environment, as shown in table.3^[7,8,9,11,12].

Table.3 Well blowout examples of some oilfields

Oilfield	Well	Depth	blowout features	Data
Daqing Oilfield	X3-3-22	175 m	Well was scrapped by kick,Pouring a lot of gas, mud, water, debris, reaching up to 35 meters of height	Author
	X7-D2-135	552 m	When Drilling to 552 meters of depth, the overflow occurred, then the blowout happened. The well was scrapped.	
Shengli Oilfield	B4	225.3 m	When Drilling, the blowout suddenly occurred, reaching up to 50 meters of heights, then well was collapsed and scrapped 80 minutes later.	Fan Zhaoxiang 2002
	CH13-X27	1133 m	Strong blowout occurred when tripping out nine column, then well caught fire,surface burst and the equipment fall into the underground..	
Jilin Oilfield	SN30	302.5 m	When making a pull until the first column, the wellhead overflowed. blowout occurred when connecting Kelly. the fire happened when killing.	Liang Fucheng 1994
	SN38	102.6 m	When making a pull until 52.76 meters, blowout happened.	
Bohai Sea	PL19-Oilfield 3	531 m	When making a pull until 374 meters, the wellhead overflowed.Then a guiding pipe sprayed a lot of gas and liquid, the height reached 8 meters to 10 meters from the wellhead.	Yang Hongbo 2004
	BZ25-1-6	780 m	When making a pull until 641 meters , mud poured from drill pipe. The height of the overflow reached 2 to 3 meters, then blowout happened.	

The Characteristics of well blowout caused by shallow natural gas: though there was great difference on the collapsing strength, failure patterns, and damage time due to the difference of geological condition, shallow natural gas type and pressure environment of the oilfield, there was still some common characters as shown following:

- Since its shallow buried depth and the formation lithology with low diagenesis, the formation pressure was increasing during the process from generation to enrichment of the shallow natural gas. Under the condition of unbalance of liquid column pressure, some disaster such as mud gas invasion, well kick and gas gushing would occur while the natural gas entered into the wellhole easily.
- It was very difficult to dispose the well blowout in a short time, since the natural gas migrates with great speed in a short distance when it enters into the wellhole;
- It can cause the frequently happening of the well blowout due to the bad characteristics of mud, pulling out the pistons during tripping out, since the formation lithology with low diagenesis, good permeability, formation expansion of water absorption Strong Mud-making Formations and so on.
- Well abandonment frequently takes place due to the collapsing of wellhole.

5. Conclusions

The shallow natural gas was in common existence in oilfield. The shallow gas generally develop on upper cretaceous Mingshui formation and the buried depth was about 200~400m in Song-liao basin. While, the shallow natural gas distributed relatively deep and the buried depth was about 600m-1200m. The shallow natural gas was composed mainly two kind factors: bacteriogenic methane, the value of $\delta^{13}\text{C}$ is lighter and whose value varies from -60‰ to -55‰; thermogenic natural gas, carbon isotope value was heavy and the value of $\delta^{13}\text{C}$ varied from -50‰ to -35‰.

The identification and evaluation of shallow natural gas reservoir can be by means of drilling, total hydrocarbon gas logging and log interpretation. Though the shallow natural gas can be gathered into reservoir and has the industrial exploitation value, the gas blowout accident and personal safety accident occurs frequently due to the influence of shallow gas during the drilling process. High attentions was paid on the exploration of shallow gas in the oilfield in recent years, whether from aspect of reservoir formation or drilling disaster.

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