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Quantitative calculation of upper limit of hydrocarbon charging resistance in sandstone carrier bed: A Case Study of the northern reservoir of the 4th structural belt, Nanpu Sag

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Abstract: In order to evaluate the controlling effect of sandstone heterogeneity on oil-bearing difference in sandstone carrier bed, from the point of view of hydrocarbon accumulation dynamics, using the empirical relationship between porosity, permeability and displacement pressure, the displacement pressure of different sand bodies of the sandstone carrier bed in reservoir conditions is calculated. By comparing with the oil-water interpretation, the upper limit of reservoir displacement pressure in the north of Nanpu 4 structure is finally determined.

Keywords: Nanpu Sag; The 4th structural belt; Displacement pressure; Difference chage.

1. Introduction

The lateral migration of oil and gas is a key geological process in the petroleum system and an important condition for controlling oil and gas accumulation. The sandstone carrier layer is the main form of oil and gas migration channel. Due to the influence of reservoir heterogeneity, the oil and gas of different single sand layers are charged differently, resulting in the difference of oil saturation[1], which is manifested by the mutual appearance of oil and water layers in each single sand body or sand group[2], or there is no uniform oil and water boundary in different lengths of oil column[3-5].Previous studies focused on the influence of physical properties when studying the differential filling of oil and gas to reservoir sand bodies. Combined with physical simulation experiments, the control of permeability difference or porosity on the fullness of oil and gas reservoirs was discussed [6-8]. It is believed that the porosity and permeability of oil reservoirs are good, which is conducive to oil and gas filling. The poor reservoir physical properties are water layers or dry layers. However, after a large number of exploration practices, the actual observed oil-water distribution will be more complex. Single consideration of permeability or porosity cannot completely distinguish the difference in the distribution of oil and water layers. For example, the permeability of some water layers or dry layers is high, but the porosity is relatively low.

If a single factor is considered, this situation ignores the dynamic mechanism of oil and gas migration and accumulation. The filling of oil and gas to the reservoir depends on the size and distribution of the capillary resistance of the carrier layer itself. Whether the oil and gas migration power can overcome the capillary resistance in the reservoir is the key to whether oil and gas can be filled [9]. The distribution of capillary resistance can reflect the difference of oil and gas filling.

The essence of oil and gas migration is the balance between buoyancy and capillary resistance. In this paper, based on the calculation formula of capillary force and the porosity and permeability data of reservoir sand bodies, the displacement pressure of different sand layers under reservoir conditions is calculated, and the relationship between displacement pressure and oil and water is compared. The influence of interlayer heterogeneity on oil and gas filling difference is studied, which is of great significance to deepen the understanding of oil and gas secondary migration and oil and gas accumulation, and effectively guide oil and gas field exploration.

2. Filling mechanism of oil and gas to carrier bed

Oil and gas enter the reservoir and migrate in the carrier layer, mainly in the free phase. Under hydrostatic conditions, the migration power is mainly buoyancy. Because the migration of oil and gas in the sandstone carrier layer is the process of non-wetting phase fluid displacing the wetting phase, it is inevitably hindered by capillary force. Therefore, if the weak effects of the adsorption force on the surface of rock particles and the friction force between oil molecules are ignored, the buoyancy of oil in water (Pb) is the main driving force, and the displacement pressure (Pd) of the carrier layer is the main resistance.

Under deep geological conditions, the migration of oil and gas in the transport layer is mainly controlled by the interaction between oil and gas buoyancy and capillary resistance of the transport layer.

Buoyancy (Pb) is determined by the density difference between oil and gas and formation water. It can be calculated by Formula (1) through the density of underground oil and water, or by well test pressure measurement.

$$Pb=(\rho w-\rho o)gh=\triangle\rho gh \quad (1)$$

where ρw and ρo are the density of formation water and crude oil, g is the gravity constant, and h is the height of continuous oil column. The difference between formation water pressure gradient and migration crude oil pressure gradient is buoyancy gradient (△ρgh).

The capillary pressure (Pc) of the reservoir rock is calculated by the pore throat radius (R) of the rock, the oil-gas-water interfacial tension (σ), and the contact angle (θ)

between the oil-water interface and the rock:

$$Pc=2\sigma\cos\theta/R \quad (2)$$

Displacement pressure (Pd) is the minimum pressure required for oil and gas to enter the rock through the largest connected pore network and migrate [10]. It is usually the capillary pressure corresponding to the oil saturation of 10 % in the water-bearing reservoir rock.

Aiming at the problem that the capillary pressure data of reservoir is very limited, the displacement pressure (Pd) is obtained indirectly by using the empirical formula between sandstone porosity, permeability parameters and displacement pressure [11]:

$$\text{Log } Pd=0.459+0.5 \text{ LogK}-0.385 \text{ Log}\Phi \quad (3)$$

K is permeability and Φ is porosity.

The capillary pressure curve is obtained by mercury intrusion method under experimental conditions, and it needs to be converted to reservoir conditions to truly reflect the capillary resistance in the formation [12].

$$Pc=\frac{\sigma_{ow}\cdot\cos\theta_{ow}}{\sigma_{Hg}\cdot\cos\theta_{Hg}}\cdot P_d \quad (4)$$

In the formula, PcR-capillary pressure in reservoir state,MPa; Pd-capillary pressure (calculated by physical property data), MPa; σHg-interfacial tension (between mercury and mercury vapor), 480.0 m N/m ; σow-interfacial tension between oil and water under reservoir conditions, the value is 30.0mN/m ; the wetting contact angle between θow-oil-water interface is 0° ; the wetting contact angle of θHg-mercury with rock is 140 °.

Substituting the above parameters into Formula (4), the capillary pressure under the reservoir conditions of Dongying Formation in Nanpu Sag is obtained:

$$PcR=0.082 \text{ PcHg} \quad (5)$$

In order to obtain the capillary resistance of reservoir sandstone in the formation, the displacement pressure of different sand layers under reservoir conditions is calculated according to formula (5) by using the porosity and permeability data of Dongying formation of No.4 northern reservoir exploration and evaluation well in Nanpu sag.

3. 2 Upper limit of reservoir resistance in the north of Nanpu 4th belt

Nanpu No.4 structural belt is located in the east of Nanpu oilfield (Fig.1). The overall exploration degree is relatively low and the exploration prospect is broad[13]. The area is controlled by multi-stage tectonic activities in Nanpu Sag, and multiple sets of reservoir-cap assemblages are developed in Dongying Formation and Shahejie Formation. Since 2008, exploration breakthroughs have been made in Nanpu 2-52 well, Pugu 1 well and Pugu 2 well in Dongying Formation and Sha 1 member successively, and the middle and deep layers have become important replacement areas for further exploration.

The northern reservoir of No.4 structural belt in this study is mainly Nanpu 2-52 well area (figure 1). The north of this area is adjacent to Linque sub-sag. The oil and gas are derived from the source rock of the first member of the Shahejie Formation in the northern Linque sub-sag, which is a typical lateral migration and accumulation. At present, the exploration practice shows that the oil and gas in this area are mainly distributed in the bottom of the second member of the East and the upper part of the third member of the East. The reservoir is mainly fan delta sandstone. The updip direction of the reservoir is blocked by faults, which is a fault lithologic reservoir (figure 2).

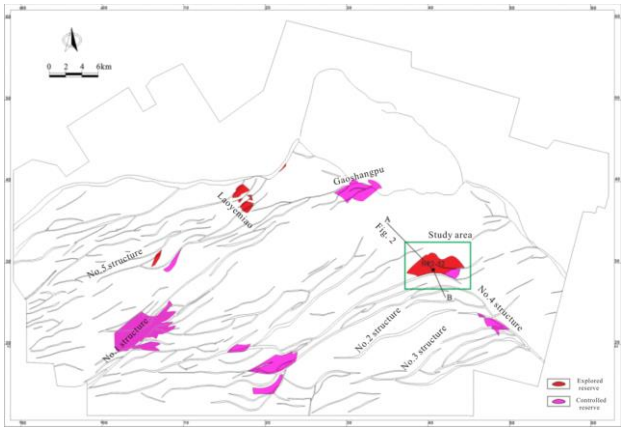


Fig.1 Location map of the study area

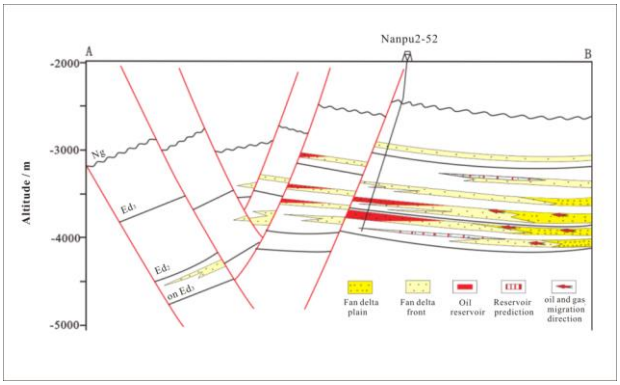


Fig.2 Reservoir profile of northern reservoir in Nanpu No.4 belt

Oil and gas migrate laterally in a carrier layer. Some sand bodies are oil layers, and some sand bodies are dry layers or water layers. If the influence of physical properties on oil and gas filling is simply considered, the difference of oil content in sand layers cannot be distinguished. As shown in Fig.3, the porosity and permeability of No.4 sand layer in the lower part of the second member of Nanpu 2-52 well are relatively high, but the logging interpretation results are dry layers. Whether the oil can be charged to the reservoir depends on whether the buoyancy generated by the oil column can overcome the reservoir displacement pressure. If the buoyancy of oil and gas migration is assumed to be the same in the same transport layer, the greater the displacement pressure, the more difficult it is to charge oil and gas. Therefore, by calculating the displacement pressure of the well under different sand reservoir conditions, it can be seen that the oil layer can be well distinguished from the water layer and the dry layer by using the displacement pressure value. The calculated displacement pressure of the oil layer is less than 0.4Mpa, and the displacement pressure of the water layer and the dry layer is greater than 0.5Mpa. Therefore, the upper limit of capillary resistance of sandstone accumulation in Dongying Formation is 0.4Mpa.

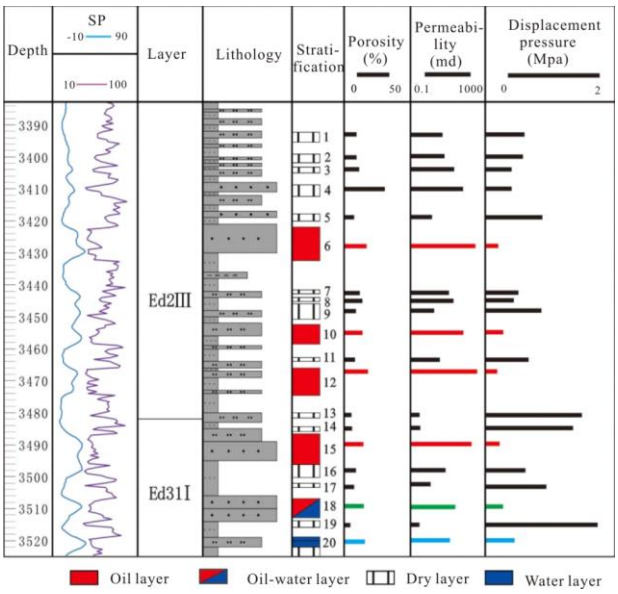


Fig.3 The relationship between oil-water layers interpretation and displacement pressure of carrier bed of NP 2-52 well

On this basis, we further selected the exploration and evaluation wells in the northern oil and gas reservoirs of the No.4 structural belt, and statistically analyzed the porosity and permeability of the sand layer in the lower part of the second member of the East. The empirical relationship between displacement pressure and porosity and permeability was used to calculate the displacement pressure of single sand body under reservoir conditions, and the corresponding relationship between displacement pressure and oil-water distribution was statistically analyzed. The results show that the porosity of reservoir sandstone is generally 5-20%, the permeability is generally 0.2-30md, the calculated displacement pressure of water layer and dry layer is in the range of 0.5-1.6Mpa, and when the displacement pressure of reservoir sandstone is greater than 0.8Mpa, all of them are dry layers, and the calculated displacement pressure of oil layer is generally less than 0.41Mpa (Figure 4).

Therefore, the upper limit of controlling oil and gas differential charging resistance in the Dongying Formation in this area is calibrated to be 0.41Mpa. It is verified that among the 77 sand layers, the calculated displacement pressure of three oil layers is higher than 0.41Mpa, between 0.5 and 0.65, and the rest are less than this boundary. Therefore, the correct rate of the upper limit of effective reservoir resistance is 83.3%. The upper limit of reservoir capillary resistance calculated to control oil and gas filling is relatively reliable. The reason why a small number of oil layers are higher than the limit value may be that there are errors in logging interpretation results or physical property interpretation.

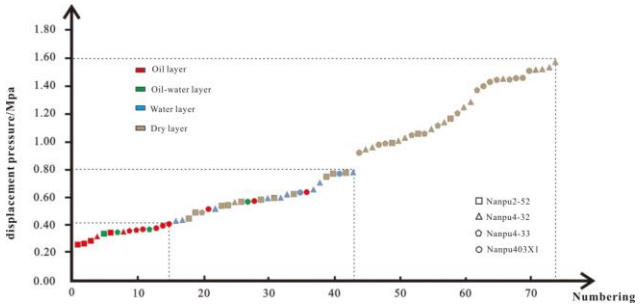


Fig. 4 Statistical diagram of relationship between displacement pressure and oil-water layers interpretation

According to the above accumulation rules, oil and gas are charged to the reservoir, and the sand body with the smallest resistance becomes the first place for oil and gas to be charged, which may form oil layers or oil-water layers. The sand body with relatively large displacement pressure has large resistance, and oil and gas are not easy to charge, becoming dry layer or water layer.

4. Conclusion

Oil and gas are charged to the reservoir sand body along the carrier layer, and the oil-bearing properties of different sand bodies in a carrier layer are also different. Sometimes the oil and water layers appear alternately, depending on whether oil and gas migration can overcome the capillary resistance of the reservoir to enter the reservoir. The reservoir of Dongying Formation in the northern part of No.4 belt of Nanpu sag is characterized by low porosity and low permeability, and the capillary resistance is large, which is an important resistance effect on oil filling. It is an effective method to evaluate the oil-bearing property of reservoir by using the size and distribution of capillary resistance in reservoir to study the differential filling law of oil and gas.

Based on the empirical relationship between porosity, permeability and displacement pressure, the displacement pressure under different sand reservoir conditions in the transport layer is calculated. By comparing with the oil-water display, the upper limit of displacement pressure in the northern reservoir of Nanpu No.4 structure is determined to be 0.41 Mpa, and the coincidence rate is 83.3 %. It is proved that the calculated upper limit of capillary resistance for controlling oil and gas filling is reliable.

Oil and gas are charged into the reservoir. The sand body with the smallest resistance becomes the place where oil and gas are first charged, which may form oil layers or oil-water layers. The sand body with relatively large displacement pressure has large resistance and is not easy to charge oil and gas, becoming dry layers or water layers.

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