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Discussion on the Irreducible Water Saturation and Ultra-Low Water Saturation

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Abstract: Irreducible water saturation is one of the important parameters for distinguishing hydrocarbon gas reservoir and water layer. The influencing factors of irreducible water saturation of sandstone reservoir and the advantages and disadvantages of the measurement method of irreducible water saturation are summarized systematically; respectively from the formation reason of ultra-low water saturation, geological significance and reduce aqueous phase trapping damage methodsto introduce the ultra-low water saturation phenomenon. The results of the study show that semi permeable diaphragm method most commonly used and more accurate measuring; bound water saturation measurement method cannot determine tight reservoir ultra-low water saturation, ultra-low water saturation in the presence of severely reduced gas permeability, producing an aqueous phase trapping damage.

Key words: *irreducible water saturation; ultra-low water saturation; nuclear magnetic resonance; semi permeable separator*

I. INTRODUCTION

Irreducible water saturation is an important parameter for reservoir evaluation. In the oil migration, reservoir formation process, due to capillary action and the rock particle surface adsorption of water, oil may not drive all the water, water survives, thus in the reservoir formedof bound water [1], usually oil test confirmed grasp for oil and gas, or comprehensive analysis does have oil and gas producing and does not produce water storage layer of water saturation as the irreducible water saturation of the reservoir [2]. The accurate measurement of the irreducible water saturation of reservoir has an important guiding significance for reservoir evaluation and oilfield development program. Tight sandstone gas production accounted for about one-fifth of China's annual natural gas production, resources in the amount of more than $100\times10^{12}m^3$, has become a major force in the supply of natural gas [3], the tight sandstone gas reservoirs exist ultra-low water saturation phenomenon, irreducible water saturation measurement method cannot determine the ultra-low water saturation values, and super low water saturation causes of mud filtrate invasion and intrusion velocity increasedin drilling and fracturing process, aqueous phase trapping damage is aggravating.

II. INFLUENCING FACTORS OF IRREDUCIBLE WATER SATURATION

Irreducible water saturation is one of the important parameters of oil layer and water layer division, the irreducible water of sandstone reservoir is mainly composed of micro pore water and film retention water, Many factors affect its content,In general, irreducible water saturation decreases with the increase of porosity and permeability;influence of particle size on irreducible water saturation has two main aspects one is the influence of the thickness of the grain, pore and throat size is two, the thickness of the grain determines the specific surface area of particles, so the particle size is small and the bound water saturation, irreducible water saturation with increasing clay or silt content increases [4]; micro pore structure is more complex, more micro pore throat, bound the greater the water saturation; temperature on different lipophilic and irreducible water saturation of rock has the effect of hydrophilic, lipophilic pore surface adsorption of polar molecules by high temperature removal The adsorption position is replaced by water molecule, which leads to the increase of irreducible water saturation. The water distribution of the water film and the temperature increase, the electrostatic adsorption effect becomes weak, which leads to the thinning of the water film, which decreases the saturation of irreducible water. Also changes in temperature also affects the size of capillary pressure, thereby affecting the irreducible water saturation of the size of the [4-5]; hiding power is also influencing the irreducible water saturation is one of the important factors, when the height of oil more than 100m, hiding power to overcome small capillary resistance, flooding small pores in the film for the retention of water, the bound water saturation reduce [6]. There are many factors that influence the saturation of irreducible water, which should be paid attention to in the evaluation of the reservoir.

III. MEASUREMENT METHODS OF IRREDUCIBLE WATER SATURATION AND ITS ADVANTAGES AND DISADVANTAGES

There are many methods for the determination of irreducible water saturation at present:

(1) Drying method (or air dry): first the vacuumized and saturated rock formation water, and then placed in the drying oven to dry off the water, and continue to use mass balance measurements of rock samples varied until the rock mass to meet the required saturation corresponding core weight[7-8].

(2)Dry gas displacement method: the saturated rock samples after loading core holder, the dry gas at a certain confining pressure and differential pressure displacing rock samples until the water content unchanged[4、9].

(3) Add moisture displacement method: make use of moisture displacing the water in the rock sample [10].

(4) Centrifugal method: the saturated formation water samples on the rotational speed of the centrifuge, by centrifugal force to overcome the capillary force of the reservoir layer to remove the water in rock samples, then weighing scales measuring irreducible water saturation.

(5) Mercury method: with mercury method to determine capillary pressure curve. First rock samples dried and evacuated, then the mercury under increasing pressure to be pressed into the rock samples, the mercury into the pores must first overcome the pore system of the capillary pressure, and the injection of mercury process is the measurement of capillary pressure.The mercury injection pressure at each point represents a corresponding pore size of capillary pressure, the number of mercury into the pores of the representatives the respective pore size in the pore system of communicating pore volume [11].

(6) NMR: For indoor experimental NMR measurements irreducible water saturation has mainly T_2 spectrum area ratio method and T_2 cutoff value method. The cutoff value is determined by the spectrum under the condition of saturated water and the spectrum of the bound water. [11-12].

(7) Crude oil displacement method: Similar to the gas drive method, the saturated rock samples after loading the core holder, with crude oil at a certain confining pressure and differential pressure displacing rock samples of water until the rock samples water content unchanged.

(8) Semi permeable diaphragm method: the partition method is to refer to the displacement of the core at the end of the placement of an oil-water separator, so that the end of the core can only out of oil.

Too many man-made factorsin the control irreducible water saturationprocess for drying method (or air dry), the accuracy is not enough; the dry gas displacement method, the displacement time is not very good control, sometimes caused by measurement error is too large; used with moisture displacement method by Cui Yingchun [10], it is proved to be a kind of effective method, but it is difficult to determine the extent of gas humidification; Centrifugal method is not good to determine the centrifugal speed of tight core, and the measurement error is large;Determination of irreducible water saturation by mercury injection curve is generally low, and Mercury itself is toxic, the core after using the mercury intrusion method cannot be used; NMRbound water saturation measurement is an effective experimental method, but there are also disadvantages of uncertain centrifugal speed; semi permeable plate method, core terminal clapboard, due to oil cannot be released to release the pressure, so can only enter the smaller pore throat, thereby discharging more cores water, so the use of semi permeable diaphragm method measured the irreducible water saturation is closer to the original formation condition [4], but semi permeable diaphragm method applies only to oil flooding water, gas flooding water separator doesn't work, and the effect of semi permeable diaphragm method for dense core is not good, because the partition in larger displacement pressure easily broken.

IV. EXISTING PROBLEMS

4.1Ultra low water saturation in gas reservoir

The main driving force for natural gas migration in the low permeability and tight sandstone reservoir is the abnormal high pressure formed under the influence of deposition, hydrocarbon generation and tectonic compression [13].Based on the traditional idea of capillary pressure equilibrium theory, the initial water saturation of the reservoir is almost equal to that of irreducible water saturation. However, with the development of tight sandstone gas reservoir, this traditional understanding is gradually being questioned [3].By measurement of water saturation and conventional experimental measuring the irreducible water saturation of sealed coring were compared, the experiment of measuring the irreducible water saturation to higher than that obtained from sealed core saturation, namely, the existence of super low water saturation phenomenon, so that the conventional experimental measurements of bound water saturation is unable to determine ultra-low water saturation. Ultra-low water saturation is the initial water saturation of the reservoir, which is lower than the irreducible water saturation of the reservoir.

4.2Formation of ultra-low water saturation in gas reservoirs

4.2.1Temperature and pressure effect

Gas reservoir formed over a long geological time and in the formation of initial temperature and pressure is low, but with increasing burial depth, temperature, pressure, gas carrying water ability strengthens

constantly, reservoir have more bound water is vaporized, continuously along with the transport of natural gas shift to carry out reservoir[14].

4.2.2Filling of dry gas

The less content of water vapor generated in the late hydrocarbon source rocks, and in the less saturated state, more dry gas will be injected into the reservoir in the late stage of natural gas accumulation, which leads to the evaporation and migration of the irreducible water in the reservoir.

4.2.3Fugitive gas reservoir leakage

Natural gas in under the action of tectonic compression factors along the fault and fracture development area leakage dissipation, takingaway more bound water.

V. ULTRA-LOW WATER SATURATION PRODUCED WATER PHASE TRAPPING DAMAGEANDPROTECTION MEASURES

Tight sandstone gas reservoir capillary pressure is high, with ultra-low water saturation of sandstone capillary pressure is much higher, considerable oversupply of capillary pressure are not reached irreducible water balance, in drilling and completion, stimulation and so on, water-based working fluid exposed to rock surface immediately in the capillary pressure self-absorption into the reservoir, and capillary pressure reached equilibrium, resulted in an increase in the near wellbore water saturation and seriously reduce the permeability of gas phase, aqueous phase trapping damage[3].

Tight gas reservoir exist ultra-low water saturation phenomenon, resulting in water phase trapping damage, the proposed use of the following protective measures [14-15]:

(1) The development of high quality drilling fluid, inhibiting the reservoir water sensitivity, and controlling the solid phase invasion reservoir plugging hole throat.

(2)Near balance pressure drilling operation: can slow down the filtrate into the formation.

(3)To reduce the surface tension of the system and reduce the resistance of the capillary.

(4)Negative pressure perforation technique.

VI. CONCLUSIONS

Measuring the bound water saturation, semi permeable diaphragm method most used and is more accurate for measuring; bound water saturation measurement method cannot determine tight reservoir ultra-low water saturation, ultra-low water saturation severely reduced permeability of gas phase, aqueous phase trapping damage. Various protective measures should be taken to reduce the damage of aqueous phase trapping damage.

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