Study On The Influence Factors Of Spontaneous Imbibition In Yanchang Fractured Low Permeability Reservoir

Qing Wei a, Zhiping Li, Hong Li, Ruiting Bai and Cai Wang

School of Energy and Resource, University of Geosciences (Beijing), Beijing 100083, China

[a]weiqing2013@163.com, [b]lzpoffice@126.com

Abstract

During the process of water injection development, due to the development of cracks in the low permeability reservoir, injected water flows along the cracks, leading to the high water cut in oil well, and the poor spread effect of groundwater, but the water spontaneous imbibition is beneficially good for the petroleum development. All kinds of factors will have an influence on the imbibition process of low permeability fractured reservoir, such as the tension, aging time, wettability, temperature, and so on. In this paper, through the research of spontaneous imbibition experiment, the effects of various factors on spontaneous imbibition are analyzed, and the relationships between oil recovery and time and between imbibition rate and time in the normal temperature and pressure experiment are studied, which provide guidance for the development of the fractured low permeability reservoirs.

Keywords

low permeability, Spontaneous imbibition, influence factor

1. Introduction

In recent years, in the new proven oil reservoirs, low-permeability oil reservoirs account for a large proportion. The low permeability oil and gas fields are mainly distributed in the major oil and gas fields or the main basin. The main features of the low permeability reservoir are low porosity, low permeability, low natural energy, and especially the developed natural fractures.

The random distribution of these cracks leads to the heterogeneity of the formation, which is bad for developing the reservoirs, and reduces the oil recovery of the low permeability oil and gas reservoir. Yanchang oilfield is located in the Ordos Basin, belonging to the typical three low oil field(low or extra low permeability, low pressure, real estate). The reservoir physical property is bad, the average permeability is low, the natural energy is low, the fracture develop well, the oil wells are flooded seriously, the formation pressure is low, the production pressure is difficult to guarantee, and the start pressure of injection water is high.In order to promote the sustainable development of Yanchang oil field, and realize the sustainable development of oil and gas production, the development of low permeability reservoirs or ultra low permeability reservoirs in the area of the plate becomes the important project. In the low permeability fractured sandstone reservoir, the main mechanism of water displacement is that the water in the fracture is absorbed into the matrix to displace the oil. Therefore, it is so important to study the imbibition law of the low permeability reservoir [1].Aronofsky J.S[2] was the first to derive the equation for the index relationship between the permeability and oil displacement. Brownscombe E.R and Dyes A.B[3] found that the capillary force can make the water suction matrix rock and displace crude oil.Briks[4] described the displacement mechanism of crude oil through a relative permeability model (water flooding or gas flooding).Graham J.W[5] and Mannon W[6] completed the experimental research with the triangle and square model. Mttax C. C and Parsons R.W[7] carried out the bottom water rising imbibition experiment, and obtained the curve between recovery rate and non-dimensional time. Blair P.M[8] discussed the influence of various factors on the imbibition with the numerical simulation method.At home and abroad, ZHANG Hongling[9] studied the sensitive parameters that affect the recovery degree of fractured reservoir. ZHU Weiyao studied the effect of imbibition and displacement on the recovery degree and the optimum seepage velocity, during water flooding. Many scholars have carried out the experiment of the imbibition mechanism, such as ZHOU fengjun[11], CHEN Gan[12], WANG Rui[13], LI aifen[14], WANG Jialu[15], ZHU Weiyao[16], et al. Many factors have an influence on the imbibition, and wettability, oil and water gravity difference, initial saturation, aging time, interfacial tension are the most sensitive factors in the imbibition process. Therefore, it is of great significance to master the influence extent and influence scope of those factors in the imbibition process.

2. Spontaneous Imbibition

Usually the process that a kind of the wetting phase fluids in porous media rely on capillary force to replace another kind of non-wetting phase fluids is known as imbibition process. The imbibition process is actually the exchange of oil, gas and water between in the matrix and crack. The fluid in the matrix flows through the crack and flows out through the wellbore, the displacement agents are injected directly into the crack or the injection fluid in the crack enters the matrix to replace the hydrocarbon(Figure 1). The imbibition process includes forward and reverse imbibition. Reverse imbibition effect is more obvious, and the oil and water exchange efficiency is higher.

$$q = \frac{\alpha \rho k_m}{\mu}(P_m - G_0 - P_f) \tag{1}$$

Where q is the volume of underground fluid of the unit time through a cross section, cm^3/s, α is the shape factor to characterize the development of fracture, $1/cm^2$, ρ is the underground fluid density, g/cm^3, Km is the effective permeability of matrix rock, Darcy, μ is the underground fluid viscosity, mPa s, Pm is the pressure in matrix, 10^{-1} MPa； G_0 is threshold pressure gradient, MPa/cm, and P_f is the pressure in crack, 10^{-1} MPa.

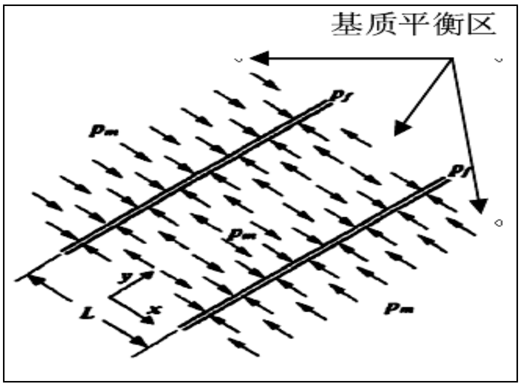

Fig. 1 The simplified flow model of matrix and fracture

In the process of water injection development in the fractured reservoir, the injection water is pushed along fractures under the action of flow pressure gradient, at the same time, the water entering the cracks is sucked into the rock and displaces oil from the matrix rock mass. Obviously, the capillary force is one of the driving forces for oil displacement, and the capillary force expression is as follows:

$$Pc = \frac{2\sigma \cos\theta}{r} \tag{2}$$

Where, σ is the interfacial tension; θ is the wetting contact angle; r is the capillary radius.

Smaller the rock capillary radius is, better the capillary imbibition power and efficiency. However, in the actual process of oil displacement, whether imbibition oil displacement force takes into effect depends on the two conditions, on the one hand, it should overcome the capillary end effect between matrix and fracture system, on the other hand, the capillary radius should be greater than the adsorption thickness of liquid film on the surface of the rock solid.

3. Spontaneous imbibition experiments

3.1 Experimental materials

Rock

The rocks are natural sandstone cores of Yanchang oil field, processed into standard cores(cylinder, d=2.5cm, l=5cm), after oil-washed, drying out 72h at room temperature, then baking 96h at 110 ℃, in the end, the cores are cooled in the vacuum container. Permeability is measured through nitrogen. The cores are saturated with formation water in the core saturation device, and the core porosity is measured, according to the difference between dry weight and wet weight of cores. The physical parameters of core are as follows(Table 1).

Table 1 Basic physical parameters of cores

ID	L (mm)	D (mm)	Φ (%)	V (cm^3)	K (mD)
002-3	456	456	123	2.903	0.046
005-4	789	213	644	3.183	0.034
006-2	213	654	649	4.11	6.251
006-3	50.75	25.32	0.15687	4.009	6.185
009-1	49.84	25.36	0.16216	4.082	6.375
009-2	51.86	25.33	0.20009	5.229	0.056
009-3	39.83	25.34	0.11985	2.407	0.049
009-4	50.23	25.35	0.12082	3.063	0.052

Fluid

The fluid used in the experiment is simulated formation water and simulated oil, and in the experiment of the reservoir spontaneous imbibition, cores are pumped vacuum and fully saturated with kerosene.

Experimental equipment

Electronic balance, vernier caliper, core pumping vacuum saturation device, constant temperature box, oven, Nuclear magnetic resonance spectrometer, glass imbibition instrument, fresh-keeping film, and so on.

Core processing

Core processing process: Washing—Drying—Measuring related parameters(Size, Porosity and Gas permeability)—pumping vacuum and saturated with formation water—Measuring water permeability—Driving simulated oil to connate water—Measuring oil permeability under the condition of the connate water—ageing 24h, in the end, the processed cores are soaked in the simulated oil to use.

3.2 Experimental procedure of spontaneous imbibition

In this paper, the spontaneous imbibition both in the gas reservoir and in the oil reservoir is studied, and the used way is volume method.

Cores pre-process

Firstly, standard cores are gained by drilling, and washed with the benzene and alcohol. Secondly, standard cores are dried with the baking oven, when the oil in the standard cores is all washed clean. Finally, relative physical properties are measured, such as size, porosity, gas permeability.

Spontaneous imbibition experiment

The oil-washed and dried cores are put in the glass imbibition instrument, then imbibition liquid are added to a certain scale, in the end, the glass imbibition instrument is sealed.

Data recording

In the first 5 minutes, due to the high imbibition rate, the date is recorded per minute, the later an hour, the date is recorded every 5 minutes, and then the date is recorded half an hour. After 3 to 4 days the date is recorded each hour. In order to avoid errors, when the data is recorded, the glass imbibition instrument should be shaken lightly.

3.3 Imbibition Influence Factors

Effect of bedrock length on the imbibition

The experimental results (Fig. 2) show that different core lengths have different effects on the imbibition. When the length of the cores increases, the imbibition rate of the cores decreases. That is to say, the imbibition rate of the short core sample is faster than that of the long core. This shows that, in the low permeability reservoir, when the crack system is relatively developed, and the length of the crack is relatively short, the imbibition rate of the matrix and the fracture system is relatively fast, and it is good for water flooding.

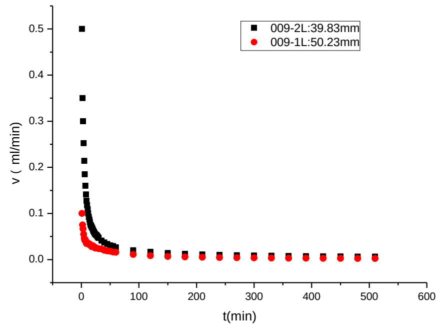

Fig.2 Effect of bedrock length on the imbibition recovery

Effect of core contact surface size between bedrock and fractures system on the imbibition recovery

Fig. 3 shows the effect of different contact surface size on the imbibition. It shows that the different contact surface have a different influence on the imbibition. The greater the open face of the core is, the greater the imbibition rate is. The imbibition rate of the both sides open cores is faster than that of the one side open cores. This shows that, in the low permeability reservoir, when the crack system is relatively developed, the contact surface size between the matrix and the fracture system will be large, so the imbibition rate of the matrix and the fracture system is relatively fast, and it is good for water flooding.

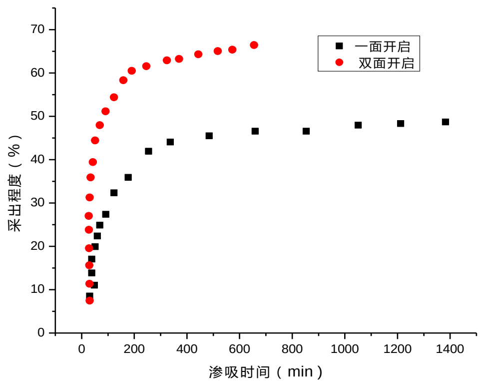

Fig. 3 Effect of core contact surface size on the imbibition recovery

Effect of wettability on the imbibition recovery

The experiment shows that, if the reservoir rock is water-wet, wetting phase fluids are generally distributed on the surface of the rock pores, and non-wetting phase fluids are distributed in the middle of the pores, at this time, the capillary pressure is the driving power. On the contrary, if the reservoir rock is oil-wet, the capillary pressure is the resistance of oil displacement. Fig. 4 shows that the imbibition degree of strong water-wet is greater than that of slight water-wet, and the imbibition degree of slight water-wet is greater than that of oil-wet.

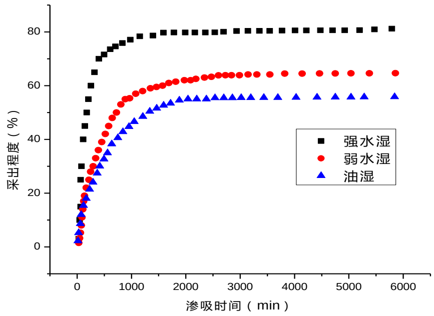

Fig. 4 Effect of wettability on the imbibition recovery

Effect of interfacial tension on the imbibition recovery

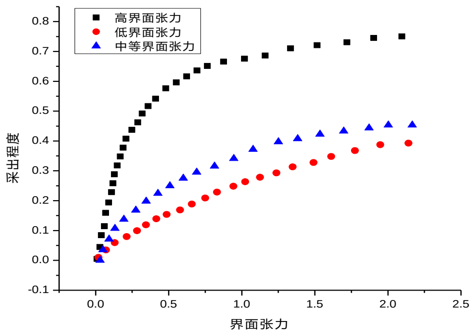

Fig.5 Effect of interfacial tension on the imbibition recovery

In view of the wide range of interfacial tension, in this paper, the effect of interfacial tension within a certain range on the imbibition is studied. Fig. 5 shows that interfacial tension is beneficial to the imbibition. In general, the imbibition recovery is enhanced by decreasing the interfacial tension. When the driving force plays the leading role, the imbibition can be ignored. If the imbibition is considered, the proper interfacial tension should be used. The large interfacial tension will lead to large seepage resistance, on the contrary, the small interfacial tension will lead to the small capillary force.

Effect of temperature on the imbibition recovery

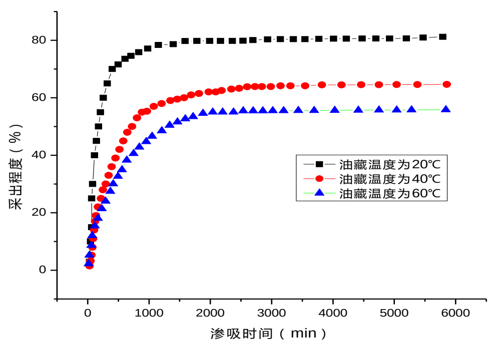

Fig.5 Effect of temperature on the imbibition recovery

Fig. 6 shows that, the higher the reservoir temperature is, the better the imbibition recovery will be. The temperature is mainly reflected in the viscosity ratio of oil and water. The change degree of water viscosity is limited, but it will significantly reduce adhesion power to reduce oil viscosity. In the higher temperature reservoir, the oil viscosity is generally not very high, and temperature gradients are generally very similar. Thus it can be seen, it will be great beneficial for the imbibition to inject hot water or steam into the cracks.

4. Experimental results and analysis

In this paper, 9 cores(002-3,005-4,006-2,006-3,006-4,009-1,009-2,009-3,009-4) are studied. It shows that wettability, aging time and interfacial tension are sensitive factors in the process of imbibition. It has an important guidable function for improving the low permeability recovery to analyze the effects of various factors on the imbibition. In the process of spontaneous imbibition, the water enters the core pore by capillary force, and discharges fluids from the pore. In order to evaluate the effect of imbibition, in the process of imbibition, the increasing value of the recovery degree in the unit time is defined as the imbibition rate, and the final recovery degree after equilibrium is defined as the spontaneous imbibition recovery. Through organizing datum, the analysis results are as follows:

Relationship between the imbibition recovery and time

According to the experimental datum, the relationship between the imbibition recovery and the time is drawn. It can be seen from the figure, in the early stage of imbibition, capillary force is larger, the imbibition rate that water is absorbed in the core is fast, and oil recovery increases sharply. With the extension of time, capillary force reduces gradually, imbibition rate is slower and slower, the water entering the core pore is less and less, until the imbibition stops, and the recovery rate tends to be constant. By fitting these curves, it can be concluded that, for gas reservoir sandstone cores, under the same conditions, spontaneous imbibition recovery and the time shows a logarithmic pattern. Recovery rate equation is as follows:

$$R=aln(t-b) \tag{3}$$

Where, R is the spontaneous imbibition recovery; t is imbibition time; a, b are imbibition characteristic value(related to the physical properties of rocks). For the low permeability sandstone reservoir, the relationship between spontaneous imbibition recovery and time is logarithmic, the physical properties of the core have an effect on imbibition recovery, and the imbibition recovery has something to do with porosity, permeability and connectivity of the pores. Due to the large porosity and permeability of gas reservoirs, in the first 12 hours of the imbibition, the imbibition amount decreases greatly; after 12 hours, the change amount of imbibition decreases gradually, and it tends to a stable value, in the end.

Relationship between the imbibition and the time

According organized experimental datum, the spontaneous rate of sandstone cores is gained, and the relation curve between the spontaneous imbibition rate and the time is drawn. As seen in the Figure, in the early stage of spontaneous imbibition, the water imbibition rate is very large. With the extension of time, imbibition rate decreases rapidly, until it tends to be stable. When the time tends to infinity, the imbibition rate becomes 0.

To sandstone cores for gas reservoirs, under the same conditions, the imbibition rate assumes exponential attenuation law versus the time. The rate change equation is as follows.

$$v = v_o + Ae^{(-x/t)} \tag{4}$$

Where, v is the imbibition rate, ml/min; v0 is the imbibition rate, when the time tends to infinity; x is the imbibition time; A is the core imbibition characteristic value (related to permeability and rock physical properties); t is the imbibition strength index.

To low permeability sandstone reservoirs, the imbibition rate assumes exponential attenuation law versus the time, and the core length and physical properties have an influence on the decay period of the imbibition rate. The attenuation law of the imbibition rate is consistent with that of the yield of the low permeability sandstone reservoir, both of which are exponential. Results show that, 1/t expresses the change of imbibition rate. The larger the 1/t is, the faster the imbibition rate is, the faster the imbibition attenuation is, and the shorter the stop time of the imbibition time will be.

5. Conclusion

Due to the low permeability, small pore radius and significant capillary pressure of the low permeability reservoir, imbibition plays an important role in the development of low permeability reservoir.

(1) It is considered that the wettability, the aging time and the interfacial tension are the most sensitive factors in the imbibition process. Through the sensitive factors, we can get some appropriate measures which are fit for capillary imbibition, such as injection of hot water, fracturing, injection of surfactant, etc. During the imbibition process, the shorter the core is, the greater the contact surface between the matrix and the crack is, and the bigger the imbibition rate. In the low permeability reservoir, the more the fractures are, the better it is for water flooding.

(2) The imbibition recovery is closely related to the boundary conditions. The imbibition recovery of the full open core permeability is the highest, followed by the both sides open cores, and the last one is the both sides closed cores. Therefore, in the development of low permeability reservoir, through horizontal and multi branch horizontal well technology, it increases the flow area to artificially increase the up and down open face and it improves reservoir imbibition, when water moves along fractures under the action of gravity, which are of great significance to improve the recovery of low permeability reservoirs.

(3) The imbibition recovery rate increases with the decrease of interfacial tension. The surfactant can enhance the hydrophilic property of the core and reduce the interfacial tension, on the one hand, which can increase the range of imbibition, on the other hand, which can improve the micro imbibition efficiency. The surfactant increases the flow rate of the oil from the matrix system to the fracture system, the utilization ratio of injection water and the oil recovery rate in the matrix system, which makes non-producing reserves developed effectively under the condition of conventional water drive.

(4) When the core is hydrophilic, during the process of water flooding, it is good for water absorption and oil drainage under the low seepage velocity, and it is good for driving force under the high seepage velocity. Therefore, there is an optimum displacement rate, which can play comprehensively the imbibition function of capillary and displacement of driving force and get the best oil displacement efficiency

(5) The relationship between the matrix rock imbibition recovery rate and time satisfies the logarithmic relationship in the normal temperature and pressure imbibition experiment, and the relationship between the matrix rock imbibition rate and time meets the exponential relationship. The capillary force is large in the early imbibition, the water absorption to core is relatively fast and the oil recovery increases largely. With the extension of time, the capillary force gradually weakens, imbibition rate is slower and slower, and the water entering the core pore is less and less. In the end, the imbibition function is over, the imbibition recovery rate tends to be constant, and the imbibition rate tends to 0.

(6) Imbibition recovery has been successfully applied in the oil field and has acquired better effect. To the water wetting low permeability reservoir, which is difficult to be developed with the method of conventional water injection, when the reservoir development program is designed, imbibition should be considered to optimize injection speed, achieve the capillary force and displacement force displacement effect and gain the best oil displacement effect. Through the methods of increasing cracks, and changing the interface tension, imbibition recovery and the velocity can increase, oil saturation in the matrix can be reduced furthest, and there will be more oil in the matrix seeping into cracks. The characteristics that the capillary imbibition of the low permeability is strong can be made full use of, production technology can be improved, and the way of development can be optimized, in order to change the disadvantage of the low porosity and permeability of the low permeability reservoir into the advantage of imbibition development. Through the ways of optimizing the injection velocity, improving the imbibition rate, increasing the imbibition and perfecting the development technology, reservoir recovery can be enhanced, and the efficient development of low permeability oil field can be realized.

References

[1] Technical counterm easures for enhancing oil recovery in low-permeability reservoir of Yanchang oil region [J]. Applied Chemical Industry ,2009,38(6): 884-887.

[2] Aronofsky J S.A model for themeehanism of oil recovery from the porousmatrix due to water invasion in fractured reservoir[J].TransAIME,1958,(213):17-19

[3] Briks ,J: A Theoretical Investigation into the Recovery of Oil from Fissured Limestone Formations by Water Drive and Gas Cap Drive, Proc.Fourth World Pet.cong.1955,Sect.2.

[4] Graham JW. Theory ang application of imbibition phenomena in recovery of oil[J]. Trans AIME, 1958, 2(16): 377-385.

[5] Mannon W. Experiments on effect of water injection rate on imbibition rate in fractured reservoir[C]. SPE4101, 1992.

[6] Mttax C C. Imbibition oil recovery from fractured water drive reservoir [J]. Trans AIME, 1962, (255) : 177-184.

[7] Blair, P.M. Caculation of Oil Displacement by Couter Current Water Imbibit ion, SPE 1475, 1960.

[8] Zhang Hongling. Research on the imbibition and its effect factors of fractured reservoir [J]. Oil&Gas Recovery Technology, 1999(6):44-48.

[9] Zhu Weiyao, Ju Yan, Zhao ming, et al, Spontaneous imbibition mechanism of Flow Through Porous Media And Waterflooding In Low Permeability In Low Permeabililty Fractured Sandstone Reservoir [J]. Acta Perolei Sinica, 2002 (11):56-59.

[10] Zhou Fengjun Chen Wenming. Study on spontaneous imbibition experiment of lowpermeability core [J]. Complex Hydrocarbon Reservoirs,2009, 2(1): 54-56.

[11] Chen Jin, Song Zhili. .Imbibition Characteristic Of Rock Matrix In Huo Shao Shan Oil Field[J]. XinJiang Petroleum Geology, 1994.15(3): 268-275.

[12] Wang Rui, Yue Xiangan, You Yuan, Liang Jiwen. Cyclic waterflooding and imbibition experiments for fractured low-permeability reservoirs [J]. Journal of Xi'an Shiyou University (Natural Science Edition), 2007,22(6):56-59.

[13] Li Aifen,Fan Tianyou, Zhao Lin. Experimental study of spontaneous imbibition in low permeability core, fractured reservoir[J]. Oil&Gas Recovery Technology, 201l,8(5):67-69.

[14] Wang Jialu, Liu Yuzhang, Chen Maoqian, et al. Experimental study on dynamic imbibition mechanism of low permeability reservoirs [J]. Petroleum Exploration And Development, 2009, 36(1):6-90