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Research Article

Effect of Contact Time and Gas Component on Interfacial Tension of CO_2/Crude Oil System by Pendant Drop Method

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Pendant drop method has been used to measure the equilibrium interfacial tension and dynamic interfacial tension of CO_2/crude oil system under the simulated-formation condition, in which the temperature is 355.65 K and pressure ranges from 0 MPa to 30 MPa. The test results indicated that the equilibrium interfacial tension of CO_2/crude oil systems decreased with the increase of the systematic pressure. The dynamic interfacial tension of CO_2/original oil, CO_2/remaining oil, and CO_2/produced oil systems is large at the initial contact and decreases gradually after that, and then finally it reaches dynamic balance. In addition, the higher the pressure is, the larger the magnitude of changing of CO_2/crude oil interfacial tension with time will reduce. Moreover, by PVT phase experiment, gas-oil ratio, gas composition, and well fluid composition have been got, and different contents of light components in three oil samples under reservoir conditions have also been calculated. The relationship between equilibrium interfacial tensions and pressures of three different components of crude oil and CO_2 system was studied, and the higher C_1 is, the lower C_2–C_{10} will be, and the equilibrium interfacial tension will get higher. Therefore, the effect of light weight fractions on interfacial tension under formation conditions was studied.

1. Introduction

The EOR technology of gas injection is theoretically better than water injection in the enhancement of oil recovery. Gas injection has developed rapidly in recent years overseas, and it has become the most important EOR method besides thermal recovery [1–3]. There are a variety of gases that can be injected, and CO_2, for its wide sources and good flooding effect, has been widely put into practical application in oil fields [4–7]. When CO_2 is in a supercritical state, at the temperature above the critical temperature of 31.26°C and the pressure higher than the critical pressure of 7.2 MPa, its property will change. The density of CO_2 is close to liquid, and the viscosity of it is close to gas at this condition; moreover, the diffusion coefficient of the CO_2 is 100 times higher than liquid. Therefore, CO_2 has a great ability to dissolve in liquid [8–15]. This is helpful in improving the overall mass transfer rate when supercritical solubility increases and the reservoir structure is conducive to increase inner diffusion and external diffusion, in order to increase the opportunity of the contact of CO_2 with oil and make them easier to mix. Therefore, CO_2 miscible flooding can meet the requirements for injected solvent in many oil fields [16–22].

The data of gas and crude oil interfacial tension under conditions of formation has very important theoretical and practical value, and the key of miscible flooding technology is to determine the minimum miscibility pressure of injection agent and crude oil [23–27]. The phenomenon that the interfacial tension changes with pressure significantly affects the reservoir fluid transfer behavior [28–31]. Miscible flooding technology is considered as one of the most cost-effective methods of EOR [32–35].

Pendant drop has been used to measure the relationship between the equilibrium interfacial tension and the pressure of CO_2/crude oil system under the condition of the stratum temperature. Changes of interfacial tension with time

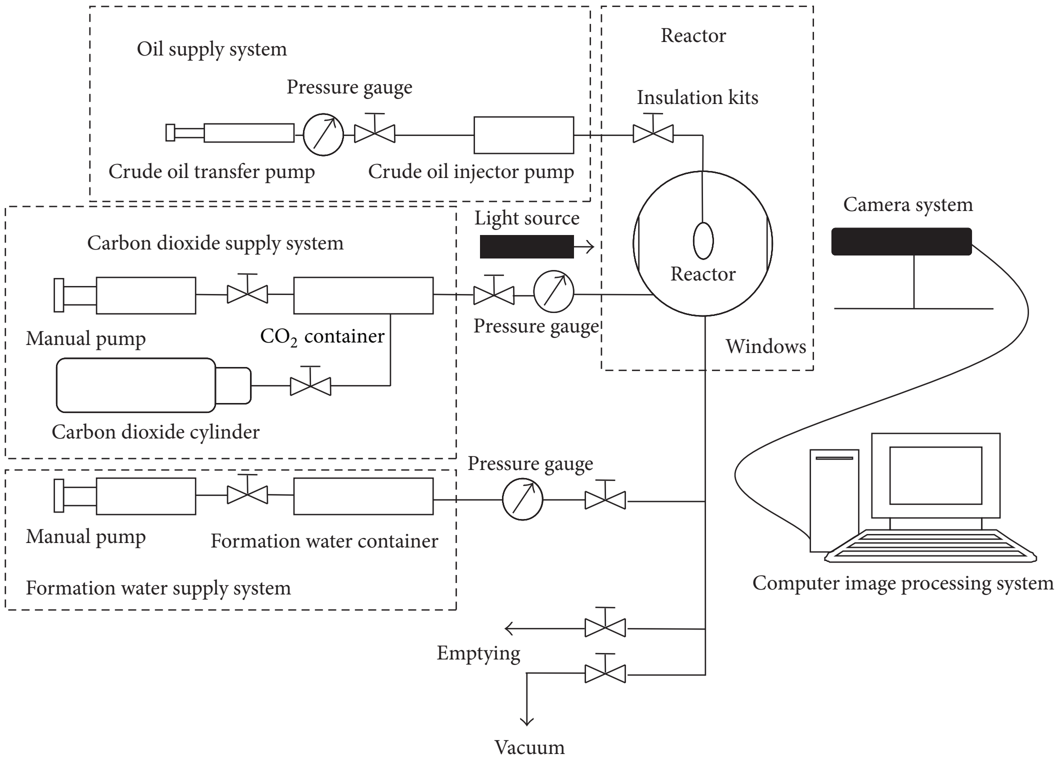

Figure 1: The schematic for the determination of interfacial tension by pendent drop method.

and pressure were measured by this method. By PVT phase experiment, the gas-oil ratio, gas composition, and well fluid composition have been measured. And the effect of light weight fractions on the interfacial tension under formation conditions was also calculated.

2. Experiment

2.1. Experimental Apparatus. High temperature and pressure interfacial tension meter has been used in the experiments, made by a French production company ST. The core of the device is a reactor with a window, which has an operating temperature of 0~200°C and a maximum working pressure of 70 MPa. Diameter of the needle used in the experiment is 0.81 mm, which is used for hanging droplets and using PVT analyzer for routine analysis.

Pendant drop method technology is the most accurate method to measure the interfacial tension under high temperature and high pressure conditions. First, the pump is used to form droplets on stainless steel needle department, and then the droplets shape photos are shot by amplifying camera system; after that the computer image processing systems are used to get the outer contour of the oil droplets. Ultimately calculated the interfacial tension, by using corrected image magnification, the density of light phase and heavy phase. The apparatus is shown in Figure 1.

2.2. Experimental Samples. Crude oil was provided by Zhongyuan oilfield, and formation temperature was 355.65 K. Experiment with CO_2 gas was produced by Beijing Hua Yuan Co. with a purity of 99.995% and petroleum ether was produced by Sinopharm Chemical Reagent Company.

3. Experimental Phenomena and Results Analysis

3.1. CO_2/Oil Equilibrium Interfacial Tension

3.1.1. Experimental Phenomena

(1) The Dissolution and Extraction Effect. The experimental temperature is 82.5°C, and the pressure ranged from 0 MPa to 30 MPa. During the experiment, there is a medium exchange as the oil drop from the tip of the needle interacts with the CO_2 from the reactor on the condition that the experiment pressure is higher than the bubble point pressure [16–18]. CO_2 has been dissolved into the oil droplets constantly, and the light group of oil droplets also spread to CO_2 [19–22]. At the beginning of the contact of oil and CO_2, the reaction is much stronger, and the light component of crude oil has been dissolved by supercritical CO_2 constantly [23–25], as shown in Figure 2. After some dissolution and extraction, the heavy component of crude oil will be left behind, and the crude oil and CO_2 will eventually reach equilibrium state as shown in Figure 3. The interfacial tension of this time can be seen as the equilibrium interfacial tension.

(2) The Effect of Pressure on the Dissolution and Extraction. It can be seen from the picture that, with the increase of the pressure, the extraction of crude oil increases, and the

FIGURE 2: The initial phase.

FIGURE 3: The equilibrium phase.

interface between CO_2 and crude oil becomes unstable. A small amount of light components can be extracted out at the pressure of 16 MPa, but the extraction effect becomes more significant when the pressure reaches 30 MPa, as shown in Figure 4, taken at the initial state. At this time, the oil droplets gravity is equal to the CO_2/oil interfacial tension, so that the oil droplets could suspend on the needle without dripping.

3.1.2. The Experimental Curve. The relationship between interfacial tension and pressure is shown in Figure 5. The equilibrium interfacial tension between crude oil and CO_2 decreases with the increase of pressure. The minimum miscibility pressure of the system calculated by extrapolation method is 18.97 MPa. When the pressure is lower than 18.97 MPa, the interfacial tension decreased rapidly; but while the pressure reaches 18.97 MPa, the reduction of interfacial tension will get slower.

3.2. The Dynamic Interfacial Tension between Crude Oil and CO_2. The experiment showed that the interaction between CO_2 and crude oil is strong at the early stage, but with the extraction of light weight fractions of crude oil by CO_2 and the dissolution of CO_2 into the oil, the interfacial tension between them changes. In order to study the effect of this process on the interfacial tension, the contact time's effect on the interfacial tension between crude oil and CO_2 should also be tested.

TABLE 1: The equilibrium interfacial tension of three CO_2/crude oil systems.

Oil sample	Equilibrium interfacial tension/MPa
Original oil	18.9744
Remaining oil	19.4748
Produced oil	20.5144

Figures 6, 7, and 8 show how the three oil samples' interfacial tension changes with time. The oil samples include original oil, remaining oil, and produced oil. It can be seen from the figure that the interfacial tension of CO_2 and oil is large at the initial contact; but as the contact time is getting longer, the interfacial tension decreases gradually and eventually reaches dynamic balance.

Figures 9 and 10 compared the curves of CO_2/crude oil interfacial tension change with time in two different pressures. It can be seen from the figure that the higher the pressure is, the larger the magnitude of CO_2/crude oil interfacial tension changing with time will reduce. The value of equilibrium interfacial tension under 12 MPa is more than 90% of the initial interfacial tension, but it turns to 80% at the pressure of 21 MPa. Obviously, the interaction between CO_2 and oil is stronger, and the change of interfacial tension is bigger at a higher pressure. This phenomenon is due to the fact that more lightweight components are extracted out and the dynamic mass transfer is getting active at high pressure. The actual reservoir CO_2 flooding belongs to multicontact miscible flooding, it's a process that after the contact of CO_2 and oil, and many times extraction and dissolution, the oil and CO_2 eventually get miscible. This leads to the interfacial tension between crude oil and CO_2 which becomes an inevitable result of dynamic change.

3.3. Effects of Gas Composition on CO_2/Oil Interfacial Tension. Using PVT phase experiment, gas-oil ratio, gas composition, and well fluid composition have been got as shown in Figures 11, 12, and 13. And calculate different contents of light weight fractions in the three oil samples under reservoir condition. Contents of C_1, C_2–C_{10}, and C_{11+} of three oil samples are shown in Figure 14.

As can be seen from Figure 13, the higher the C_1 is, the lower its corresponding C_2–C_{10} will be, and the C_{11+} content of the three oil samples is relatively at a low level.

Using extrapolation method, calculate the equilibrium interfacial tension of CO_2/original oil system, CO_2/remaining oil system, and CO_2/produced oil system. The equilibrium interfacial tension of three different systems is shown in Table 1.

It can be seen from Figure 13 and Table 1 that the content of C_1–C_{10} component is continually increasing. The higher C_1 is, the lower C_2–C_{10} will be, and the equilibrium interfacial tension is getting higher. On the contrary, the lower C_1 is, the higher C_2–C_{10} will be, and the equilibrium interfacial tension becomes lower. In other words, C_1 is negative for CO_2 and oil miscibility, and C_2–C_{10} promotes the miscibility of CO_2 and oil system. Therefore, factors that affect the CO_2 and crude oil system interfacial tension are pressure, gas composition,

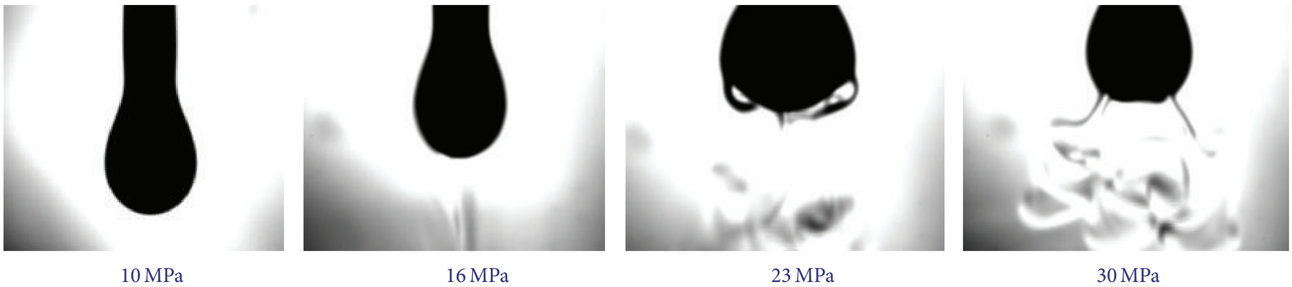

FIGURE 4: Images of the pendant oil drop in CO_2/crude oil system under different pressure.

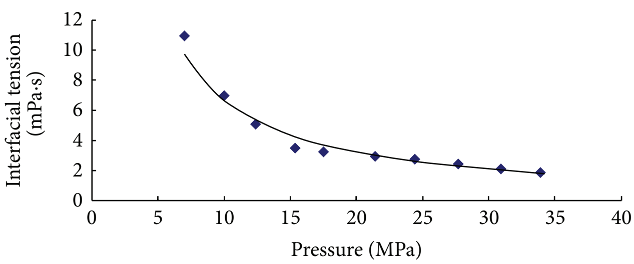

FIGURE 5: Interfacial tension of CO_2/crude oil system under different pressure.

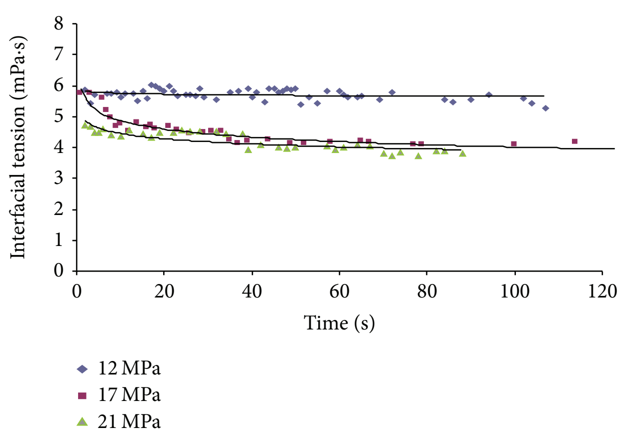

FIGURE 6: The relationship between interfacial tension and time of CO_2/original oil system.

and time. In hydrocarbons and CO_2 compound flooding process, the selection of C_2–C_{10} and CO_2 as a composite system will achieve better results in flooding.

Recent studies mostly focused on the research and application of equilibrium interfacial tension, and the study of dynamic interfacial tension is rare. But the actual reservoir CO_2 flooding belongs to multicontact miscible flooding, and this leads to the interfacial tension between crude oil and CO_2 becoming an inevitable result of dynamic change. So the dynamic interfacial tension can better simulate the situation under reservoir conditions and is more valuable. Historical studies do not mention hydrocarbons and CO_2 compound flooding, but the data from the experimental measurements are conducive to the development of hydrocarbons and

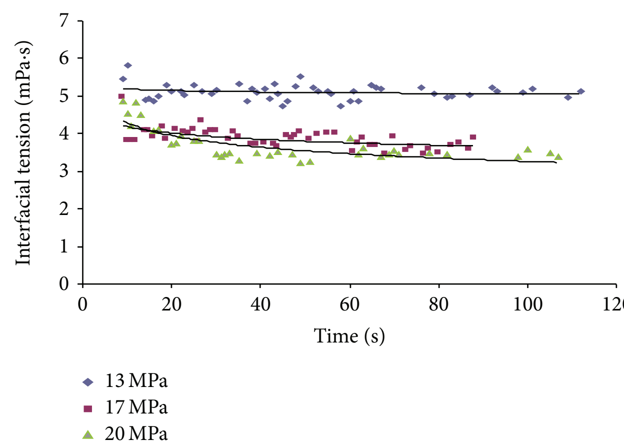

FIGURE 7: The relationship between interfacial tension and time of CO_2/remaining oil system.

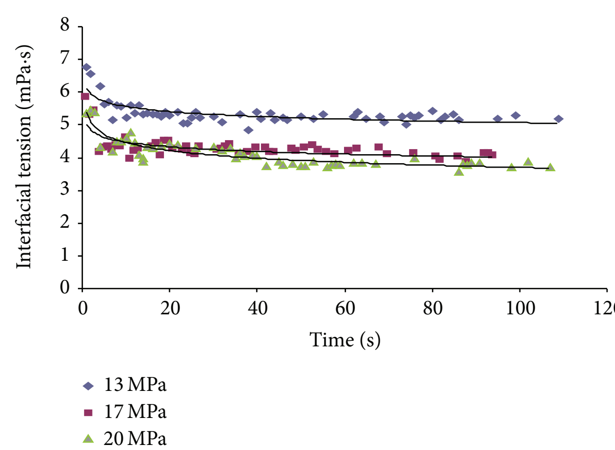

FIGURE 8: The relationship between interfacial tension and time of CO_2/produced oil system.

CO_2 compound flooding technology. The findings not only provide experimental evidence for indoor hydrocarbons and CO_2 compound flooding but also make it not just stick to a single CO_2 flooding. The experimental results provide a broad prospect for CO_2 flooding and opened up new areas for hydrocarbons and CO_2 compound flooding technology.

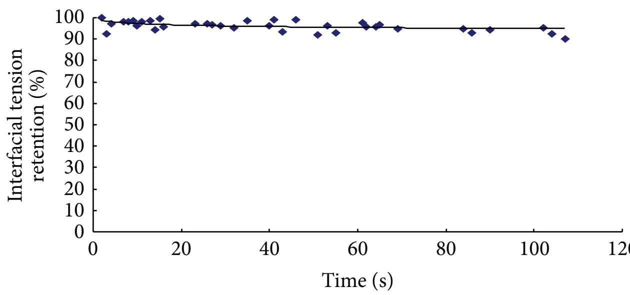

Figure 9: The curve of CO_2/crude oil system interfacial tension change with time under 12 MPa.

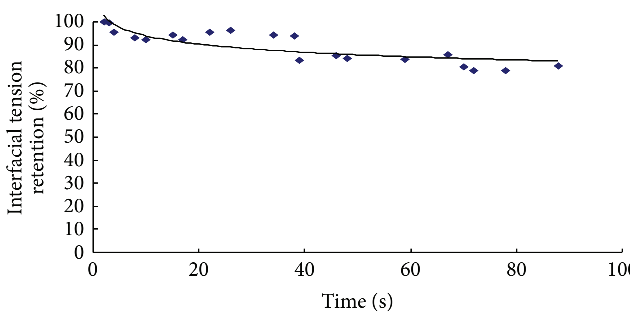

Figure 10: The curve of CO_2/crude oil system interfacial tension change with time under 21 MPa.

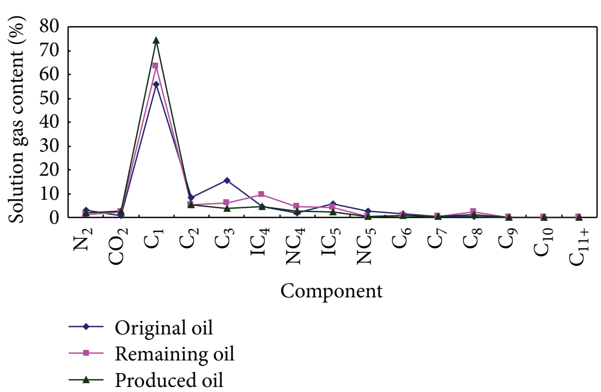

Figure 11: Gas phase composition of crude oil.

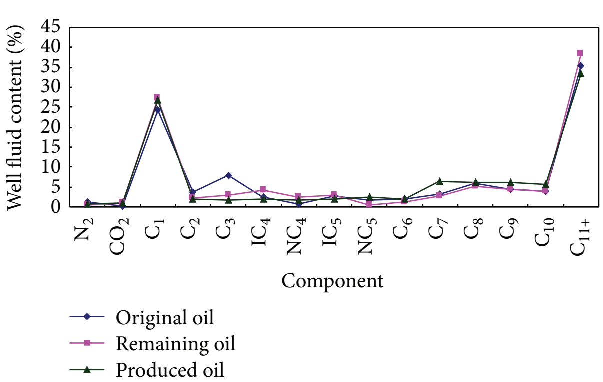

Figure 12: Well fluid composition of crude oil.

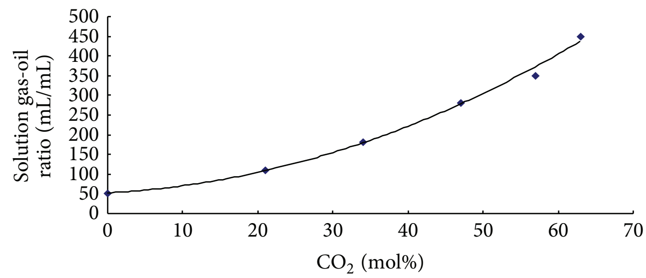

Figure 13: Gas-oil ratio of crude oil.

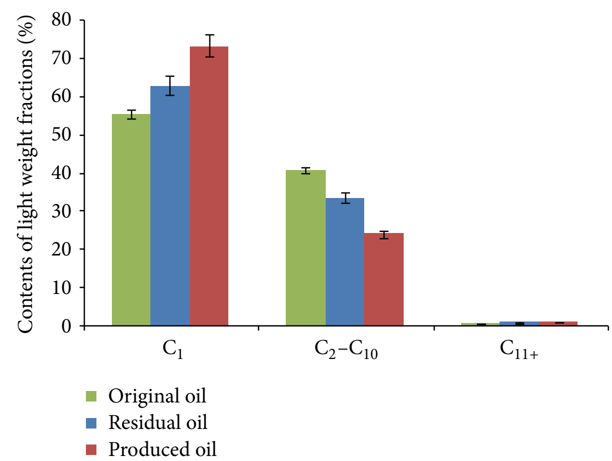

Figure 14: Content of different light weight fractions of original oil, remaining oil, and produced oil.

4. Conclusions

(1) Using the pendant drop method, the interaction between CO_2 and crude oil can be seen through the reactor under simulated-formation conditions of temperature and pressure. There is a strong mutual diffusion at the beginning of the contact of CO_2 and crude oil, and as the pressure goes higher, the dissolution and extraction become easier.

(2) Data of CO_2 and crude oil interfacial tension under conditions of the temperature of 355.65 K and the pressure ranging from 0 MPa to 30 MPa were measured by experiment. Experimental results show that CO_2/crude oil equilibrium interfacial tension decreases with the increasing of pressure.

(3) The interfacial tension of CO_2 and oil is large at the initial contact, and as time is getting longer, the interfacial tension decreases gradually and eventually reaches dynamic balance. Moreover, the higher the pressure is, the more the magnitude of changing of CO_2/crude oil interfacial tension with time will reduce.

(4) The higher the content of C_1 in crude oil is, the lower the content of C_2–C_{10} will be, and the equilibrium interfacial tension will get higher. On the contrary, the lower the content of C_1 is, the higher the content of C_2–C_{10} will be, and the equilibrium interfacial tension will become lower. In other words, C_1 is negative for the miscibility of CO_2 and oil, and C_2–C_{10} can promote the miscibility of CO_2 and crude oil system.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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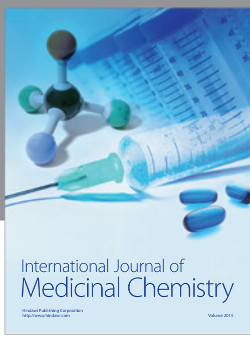
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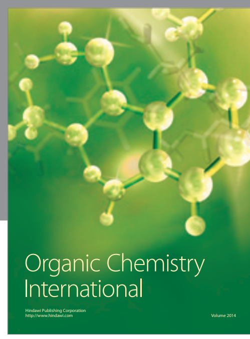
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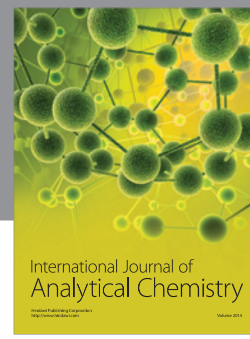
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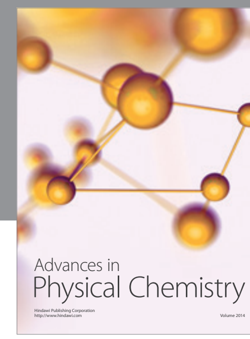
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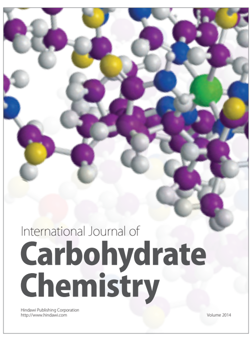
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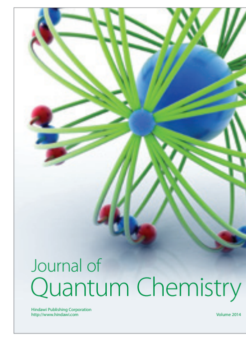
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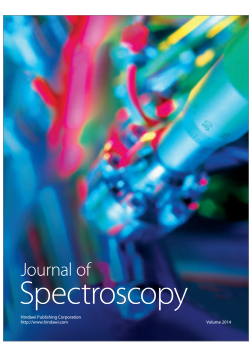
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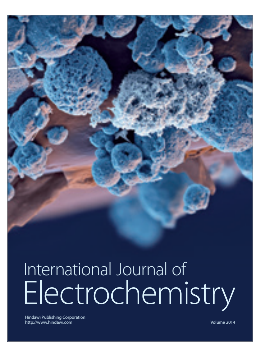
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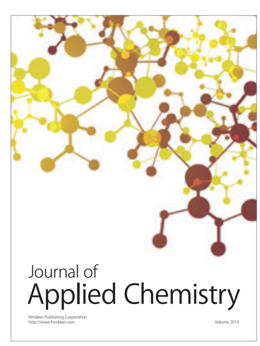
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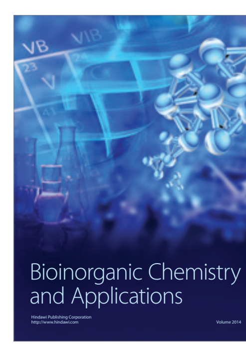
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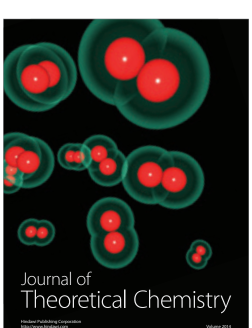
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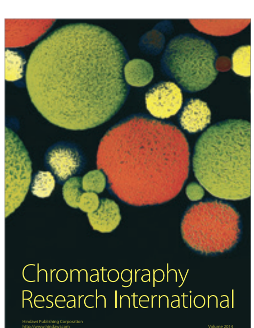
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