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# Interfacial tension of $CO_2$ and crude oils under high pressure and temperature

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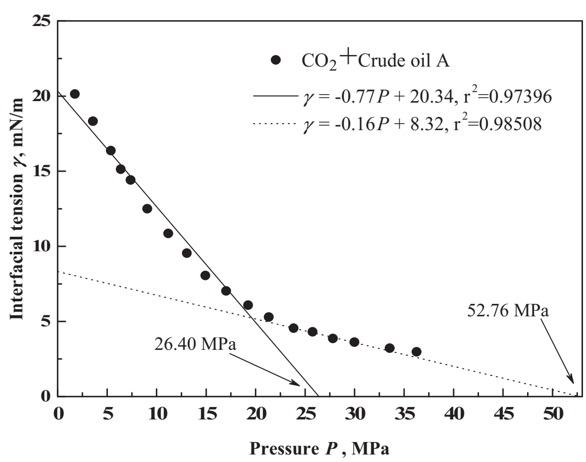
## HIGHLIGHTS

- Interfacial tension between $CO_2$ and crude oil is affected by intermolecular forces.
- For $CO_2$ + hexadecane system, the phenomenon of miscibility is observed.
- For crude oil A, the predicted minimum miscibility pressure (MMP) is 26.40 MPa.
- For crude oil B, the predicted minimum miscibility pressure (MMP) is 24.00 MPa,

## GRAPHICAL ABSTRACT

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## ABSTRACT

The interfacial tension data between $CO_2$ and reservoir crude oils were measured by the pendant-drop method and the axisymmetric drop shape analysis (ADSA) under high pressure and temperature up to 45 MPa and 412.15 K respectively. The results show that at beginning, the interfacial tension between $CO_2$ and crude oils decreases rapidly with pressure being increased, and then the interfacial tension decreases quite slowly with increasing of pressure because of heavy components in the crude oils. There is no ultra-low or zero interfacial tension obtained for $CO_2$ + crude oil systems. For comparison, the interfacial tensions between $CO_2$ and hexadecane at 318.15 K were also determined. The results show that for $CO_2$ + hexadecane system, the vanishing interfacial tension and miscible phenomenon are observed.


## 1. Introduction

$CO_2$ flooding is an enhanced oil recovery method for heavy oil reservoirs especially with low permeability where other enhanced

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oil recovery technologies are not suitable [1–3]. The utilization of $CO_2$ flooding to enhance oil recovery attracts more and more attention by petroleum engineers. Not only because of the good performance of $CO_2$ in oil recovery, but also $CO_2$ is one of the greenhouse gases which have already affected the global climate [4,5].

It has been found that for $CO_2$ flooding, the oil recovery rate can be enhanced usually up to 8–16% of the original oil in place [6,7]. The oil viscosity reduction, oil swelling effect and miscibility between $CO_2$ and crude oil are considered main contributions for $CO_2$-EOR [8,9]. Oil mobility can be improved because of $CO_2$ dissolving in crude oil which causes oil viscosity to be reduced and the oil volume expanded [10]. In the $CO_2$ flooding processes, flow behavior of crude oil, gas and brine are controlled mainly by the interfacial interactions (interfacial tension; wettability; capillarity and dispersion) among crude oil, reservoir brine, $CO_2$ and reservoir rocks [11–13]. Meanwhile the most important interaction is the interfacial tension because wettability, capillary pressure and dispersion are closely related to interfacial tension under certain condition of pressure and temperature [14–16]. Recently, vanishing interfacial tension (VIT) technique has been developed and utilized to determine the miscibility conditions of different crude oil + $CO_2$ systems [17]. The VIT technique is based on the concept that the interfacial tension between crude oil and $CO_2$ becomes zero when they get miscible. The minimum miscibility pressure (MMP) and first-contact miscibility pressures ($p_{max}$) under reservoir conditions are determined by linearly extrapolating the measured IFT versus equilibrium data to zero IFT [18–20]. Therefore it is necessary to accurately measure the interfacial tension between $CO_2$ and crude oil.

The utilization of pendant drop method of measuring interfacial tension is based on the equilibrium of static force. The axisymmetric drop shape analysis (ADSA) technique for the pendant drop method is probably the most advanced and accurate method for measuring the IFT in large range of pressures and temperatures [21].

In this work, the interfacial tension data between $CO_2$ and reservoir crude oils were measured under high pressure separately at 318.15 K, 333.15 K, 353.15 K and reservoir temperatures. For comparison, the interfacial tensions between $CO_2$ and hexadecane, at 318.15 K were also determined. Unexpectedly, in this study, no ultra-low or zero IFT is obtained of each measurement for $CO_2$ + crude oils and $CO_2$ + liquid paraffin systems. Instead, there always exists an IFT value and the miscible phenomenon is not observed. At high pressures, for these two systems, the value of IFTs as low as 2–4 mN/m are reached. For $CO_2$ + hexadecane, miscible phenomenon is observed.

## 2. Experimental

### 2.1. Materials

Carbon dioxide with a mass purity of 99.7% was purchased from Beijing AP Beifen Gases Industry Company. Hexadecane (analytically pure) was supplied by Fluka. Two samples of oil are from Shengli Oil field.

### 2.2. Experimental apparatus and procedure

For the purpose of measuring the IFT between $CO_2$ and crude oil, an apparatus containing a *PVT* cell was used. The visible pressure–volume–temperature (*PVT*) apparatus is purchased from S.T. Ltd. France. A schematic diagram of the experimental apparatus is shown in Fig. 1. Before each measurement of interfacial tension, the phase equilibrium of $CO_2$ and crude oil under desired pressure and temperature was obtained in another apparatus containing a *PVT* cell (240/1500), which is as well purchased from S.T. Ltd. France and the technical specification is described in our previous work [22]. After being saturated by $CO_2$, the density of oil is measured by density meter (DMA HPM) supplied by Anton Paar and the oil phase is sampled into intermediate container under the constant pressure and temperature. Then the saturated oil is introduced into the cylinder of the IFT apparatus which is rated to 100 MPa. The pressure of *PVT* cell was generated with an automatic pump and was measured with a pressure sensor meanwhile temperature of the *PVT* cell and the cylinder and the pipes are controlled by electric heating system. The pressure of the cylinder is increased slightly higher than that of $CO_2$ gases in the *PVT* cell so that the saturated oil drop can be introduced to the cell.

The temperature was measured with a calibrated thermocouple inside the *PVT* cell; the pressure of the system was measured with a digital pressure indicator. A high-pressure cell, rated to 100 MPa and 473.15 K, and equipped with windows was utilized for the experiment. The visible window was attached to the front and back of the cell to obtain full visibility of all the contents in the cell. The shape of oil drop in the *PVT* cell can be captured using a CCD camera-based measurement system. The pressure and temperature of the *PVT* cell can be read on the panel. The temperature can be controlled

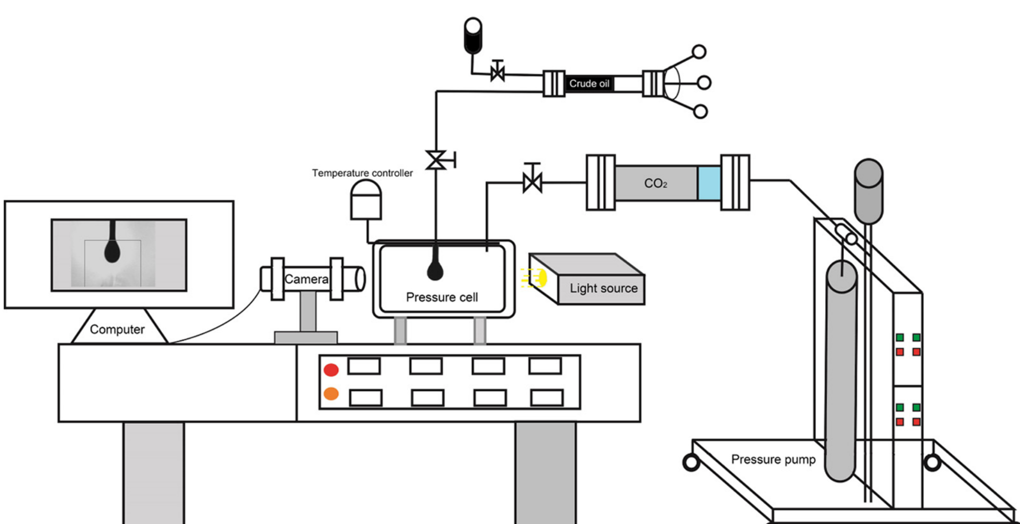


**Fig. 1.** The diagram of experimental device.