
● Short Communication

LOW-FIELD NMR DETERMINATIONS OF THE PROPERTIES OF HEAVY OILS AND WATER-IN-OIL EMULSIONS

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Low-field (<50 mT) nuclear magnetic resonance (NMR) well-logging measurements are beginning to be used to obtain estimates of oil viscosity in situ. To build an interpretive capability, we made laboratory T_1 and T_2 relaxation measurements on a suite of high-density, high-viscosity crude oils. These measurements were also used to estimate oil viscosity and water fraction from T_1 and T_2 measurements on stable, water-in-oil emulsions. High-density, high-viscosity oils have components that relax faster than can be measured by nuclear magnetic resonance logging tools. This requires corrections to T_2 logging measurements for accurate estimates of oil saturation and porosity. © 1998 Elsevier Science Inc.

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VISCOSITY OF HIGH-DENSITY OIL

The viscosity (η) of low-density oil is proportional to the inverse of the T_1 and T_2 time constants, i.e., ($\eta \sim 1/T_{1,2}$).^{1–3} Few data have been published, however, on the relationships between viscosity and T_1 and T_2 for oils with viscosity values greater than 1000 cp. Nuclear magnetic resonance (NMR) measurements were made on 12 water-free oils ($\eta > 800$ cp), as shown in Fig. 1.

For these high-density, high-viscosity (HDHV) oils, the $\eta \sim 1/T_{1,2}$ relationship no longer holds, with the T_2 values decreasing more slowly with increasing viscosity. The T_1 measurements have minimal sensitivity to increases in viscosity from approximately 1000 cp where the geometric mean T_1 (T_{1G}) starts to level off at 4.5 ms. All T_1 distributions for oil viscosity values between 1000 and 100,000 cp were fairly broad, with T_{1G} values of about 4.5 ms due probably to the low level of vibrational (“lattice”) energy available for exchange with the magnetic spins.⁴

HYDROGEN INDEX

The hydrogen index (HI) is defined as the amount of hydrogen in a sample of oil divided by the amount of hydrogen in an equal volume of pure water. The higher density crudes have a higher hydrogen content⁵ (and

have higher volumes for the same sample weight). Thus, the HI of heavy crude oils should be approximately 1, with some reduction expected for aromatic crude. The NMR estimate of HI is dependent on how rapidly the NMR signal relaxes. For HDHV oils, some of the ^1H NMR signals relax more rapidly than can be measured with the result that the inferred or apparent HI (HIA) will be less than the actual value. HDHV oils are believed to have a micelle structure in which the largest, most polar “asphaltene” components are surrounded (and stabilized) by the “resin” components of intermediate size and polarity. These micelle structures are suspended in the fluid “oil.” Protons on these structures appear to have very short relaxation time constants. For measurements at the NMR logging frequency of 2 MHz, the dead time of the MARAN2 (Resonance Instruments, Witney, UK) instrument is 70 μs , which is sufficiently long to allow as much as 50% of the relaxation to occur before the first measurement. This signal loss is seen as a decrease in the NMR-measured HIA with increasing viscosity, as shown in Fig. 2.

The signal loss due to long dead times is corroborated by measurements at 11.2 MHz (same electronics, different magnet) where the dead time is 12 μs , and the loss of signal is less than 25%.

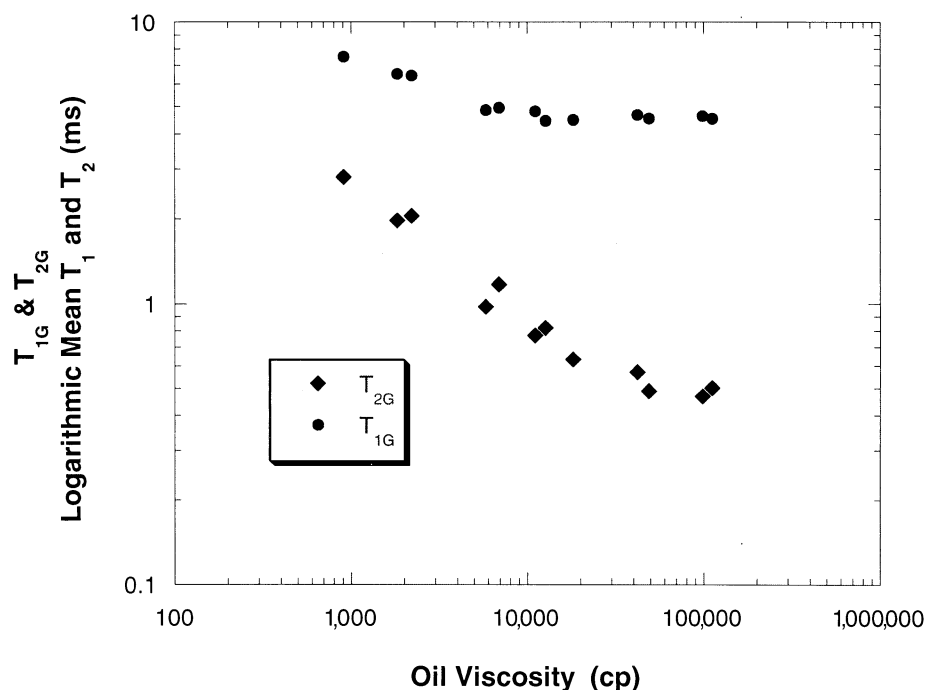


Fig. 1. Logarithmic mean T_1 and T_2 plotted vs. oil viscosity. T_2 can be used to estimate viscosity values as high as 20,000 cp.

WATER-IN-OIL EMULSIONS

The water fractions in emulsions can be determined from their T_2 distributions (Fig. 3). Because the oil signal relaxes rapidly and the water signal relaxes slowly, the T_1 and T_2 distributions tend to be bimodal.

Using the data in Figs. 1 and 2, we can obtain accurate estimates of the oil and water fraction plus the viscosity of the oil. With emulsion viscosity measurements, we can also build a transform for estimating emulsion viscosity from relaxation measurements (Fig. 4).

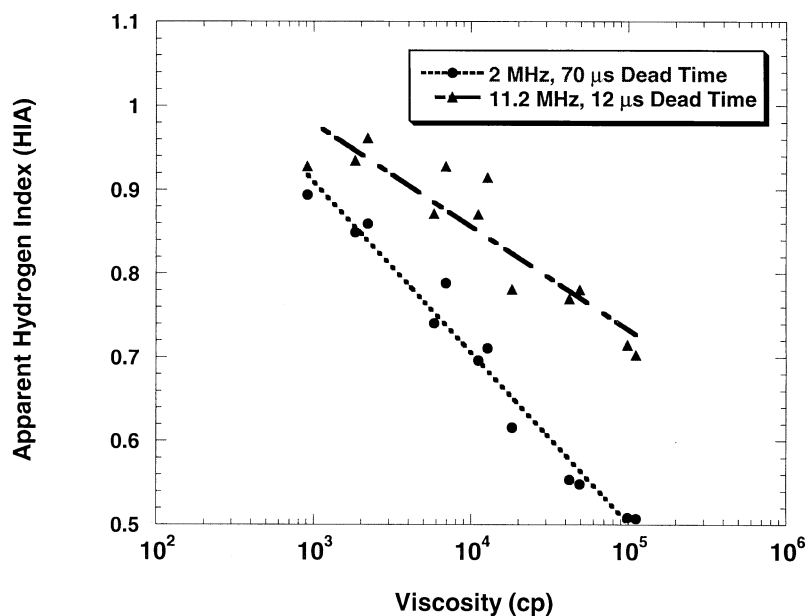


Fig. 2. HIA plotted vs. oil viscosity. HIA values significantly less than 1 indicate loss of signal due to the dead time of the NMR probe. The shorter dead time of the 11.2 MHz probe results in higher HIA values.

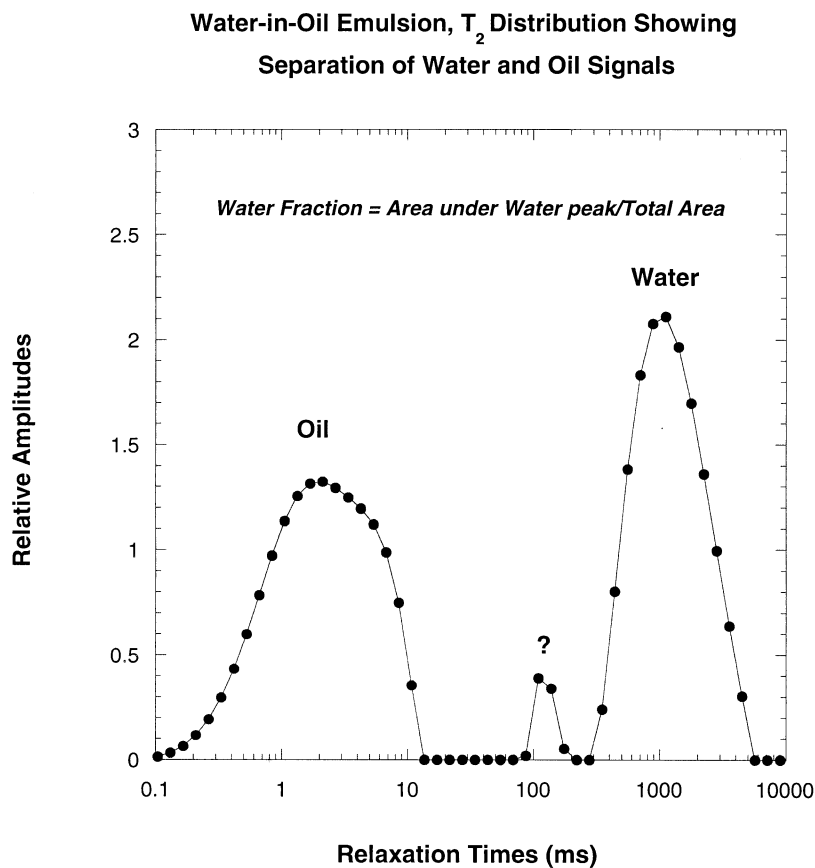


Fig. 3. T_2 distribution: signal amplitudes plotted vs. time constants. The area under the distribution curve is proportional to the amount of hydrogen detected. The area under the short time constant peak (higher viscosity) is a volumetric measure of the hydrogen signal from the oil, and the area under the long time peak is a volumetric measure of the hydrogen signal from water.

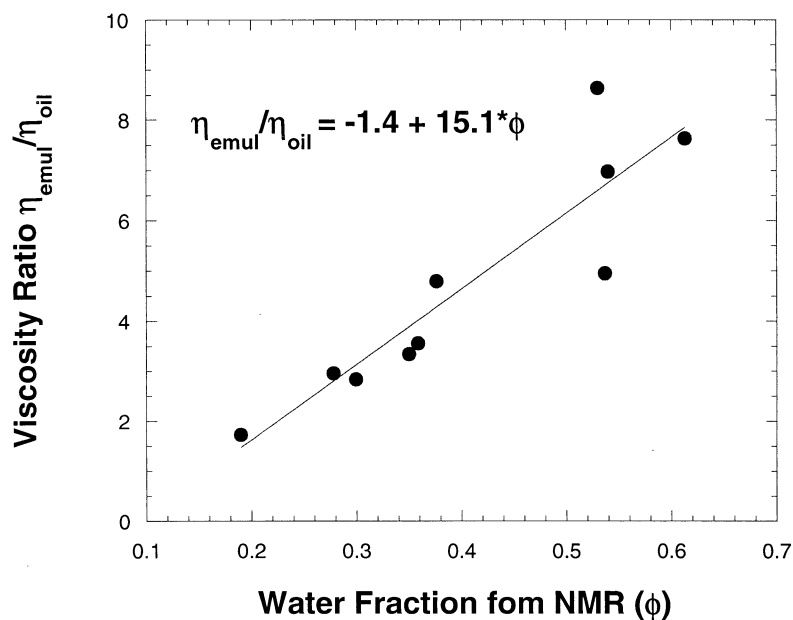


Fig. 4. The ratio of emulsion and oil viscosity plotted vs. water fraction indicates that a single T_2 measurement on a water in oil emulsion is sufficient to determine oil viscosity, water fraction, and emulsion viscosity.

CONCLUSIONS

Our laboratory results confirm that NMR logs can detect HDHV oils $>10,000$ cp, and estimate their volumes. The HIA of HDHV oils can be $\ll 1$, which would lead to an underestimate of oil fraction from NMR logs if not accounted for. A single T_2 measurement on a water-in-oil emulsion may be all that is needed to determine water fraction and oil and emulsion viscosity values.

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