

**SURFACTANT-ENHANCED ALKALINE  
FLOODING FOR LIGHT OIL RECOVERY**

Contract No. DE-AC22-92BC14883

Illinois Institute of Technology  
Chicago, IL

Contract Date: Sept. 1994  
Anticipated Completion: Sept. 1995  
Government Award: \$150,000  
(Current year)

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Reporting Period: October 1 - December 30, 1994

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FOR LIGHT OIL RECOVERY

Quarterly Report for the Period  
October 1 -December 31, 1994

By  
Darsh T. Wasan

Work Performed Under Contract No. DE-AC22-92BC14883

Document Control Center  
U.S. Department of Energy  
Pittsburgh Energy Technology Center  
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Pittsburgh, PA 15236-0940

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## OBJECTIVE

The overall objective of this project is to develop a very cost-effective method for formulating a successful surfactant-enhanced alkaline flood by appropriately choosing mixed alkalis which form inexpensive buffers to obtain the desired pH (between 8.5 and 12.0) for ultimate spontaneous emulsification and ultra-low tension. In addition, the novel concept of pH gradient design to optimize flood water conditions will be tested.

## SUMMARY OF TECHNICAL PROGRESS

The problem of characterizing emulsions in porous media is very important in enhanced oil recovery applications. This is usually accomplished by externally added or insitu generated surfactants that sweep the oil out of the reservoir. Emulsification of the trapped oil is one of the mechanisms of recovery. The ability to detect emulsions in the porous medium is therefore crucial to designing profitable flood systems. The capability of microwave dielectric techniques to detect emulsions in porous medium is demonstrated by mathematical modelling and by experiments.

This quarter the dielectric properties of porous media are shown to be predicted adequately by treating it as an O/W type dispersion of sand grains in water. Dielectric measurements of emulsion flow in porous media show that dielectric techniques may be applied to determine emulsion characteristics in porous media. The experimental observations were confirmed by theoretical analysis.

## THEORY

For a spherical dispersion of sand grains, the dielectric behavior of the porous medium can be described by Hanai's model as

$$\frac{(\epsilon_1 - \epsilon_2)^3}{(\epsilon_1 - \epsilon_m)^3} \left( \frac{\epsilon_m}{\epsilon_2} \right) = \frac{1}{(1 - \phi)^3}$$

In the modelling of a bicontinuous structure such as a porous medium, the first question to be asked is whether a water saturated core should be treated as an oil-in-water emulsion or a

water-in-oil type dispersion. The experimental data of Sen<sup>1</sup> suggests that the answer to this question is to treat the rock grains as being dispersed in water. We could therefore model the ternary system of emulsions in porous media by successive iteration of two binary systems. The effective dielectric constant of the emulsions could be determined from Hanai's model for two phase dispersions. The rock grains could then be treated as being dispersed in a fluid of dielectric constant being equal to the effective dielectric constant of the emulsions. The dielectric constant of this binary mixture could again be computed by Hanai's model. However for rock formations with little or no clay content, the dielectric constant of the rock grains will be comparable to the dielectric constant of oil. Therefore, an O/W emulsion system in porous media can in effect be modelled as a dual dispersion of sand grains and oil in water. Similarly, a W/O emulsion in porous media can be regarded as a dual dispersion of water and sand grains in oil. This approach implies that a 50% emulsion of O/W in a porous medium with a 20% porosity will be similar to a 90% O/W type dispersion. A 50% W/O emulsion, on the other hand, will be similar to a 10% W/O type dispersion. We can, therefore, expect differences in the dielectric behavior of the two systems. The computed results for the two emulsion systems with dispersed phase volume fractions of upto 60%, in a berea sandstone core with a 20% porosity shown in Figures 1-3 clearly demonstrated the differences. In Figure 4, we compare the computed loss tangent values of the two emulsions with a system containing equivalent proportions of unemulsified constituents. The differences in emulsified and unemulsified systems indicated that dielectric properties may be used to determine not only the emulsion type and composition, but also to ascertain if emulsification occurs at all.

### **Emulsion Core Flood Experiments**

Two inch square berea sandstone pieces were prepared by coating them with resin. The ends were covered with plexiglass pieces with holes drilled to allow for inflow and outflow. W/O emulsions of varying concentrations were first prepared and characterized dielectrically. Water was pumped into the core at a flow rate of 1 ft/day and the dielectric constant monitored. After breakthrough, five pore volumes of the continuous phase was pumped through to ensure complete saturation. The lowest concentrations of the emulsion was then pumped through the core. The effluent concentrations were then monitored by a cavity resonance dielectrometer. A

schematic diagram of the experimental setup is shown in Figure 5.

When the effluent concentrations matched the influent concentrations, steady state flow conditions were considered to prevail and the dielectric constant of the emulsions in the porous media recorded. The next higher concentration of emulsion was pumped through the core and the procedure repeated. For W/O emulsions, the berea sandstone core is first flooded with oil and five pore volumes of oil pumped through. To facilitate oil wetting of the core, the oil filled core was left untouched for a week. About five pore volumes of oil was pumped through before W/O emulsions were introduced.

### RESULTS AND DISCUSSION

The experimentally measured value of the dielectric loss tangent is shown in Figure 6. Differences in the dielectric properties of the two emulsion systems are clearly observed. The loss tangent of O/W emulsions in the core is considerably higher than the loss tangent of W/O emulsions, at all concentrations without any overlap for dispersed phase concentrations of upto 60%.

Analogous to the definition of the Dielectric modulus of emulsions outside the porous medium we can define a Dielectric Modulus  $P_{pore}$  for emulsions inside the porous medium as follows:

$$P_{pore} = \frac{\text{loss tangent of emulsions}}{\text{loss tangent of water saturated core}}$$

This would allow for the comparison of dielectric data obtained at different frequencies for emulsion dielectric data inside porous medium. The computed  $P_{pore}$  results are shown in Figure 7 as a function of volume fraction water. The differences in the dielectric characteristics of the two emulsion types are clearly defined in the plot.

Both the experimental and theoretical values clearly establish the feasibility of determining emulsion characteristics by dielectric measurements in the microwave region.

### REFERENCES

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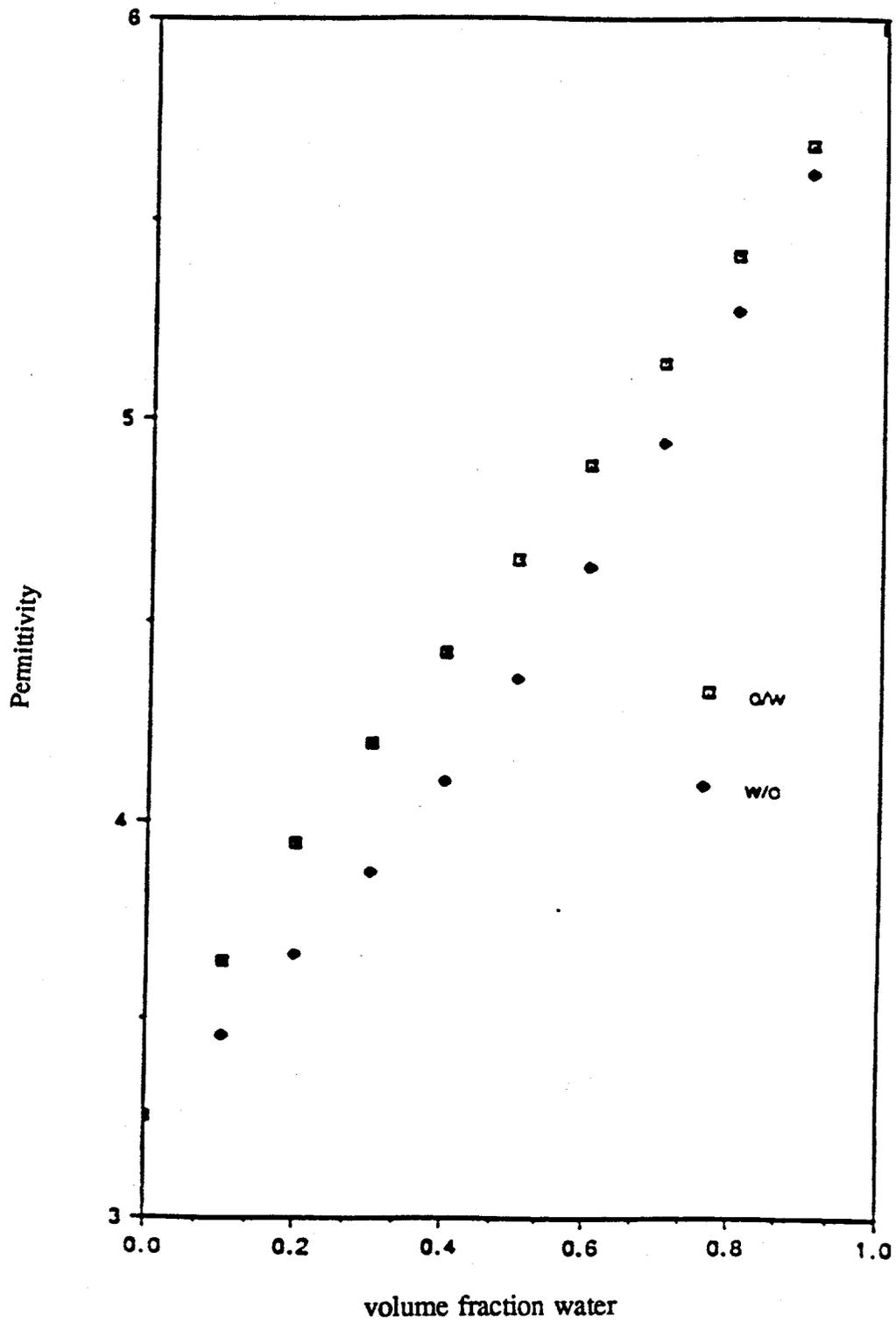


Figure 1. Computed Permittivity values at 23.45 GHz for O/W and W/O emulsions inside Berea Sandstone Core with a 20% porosity

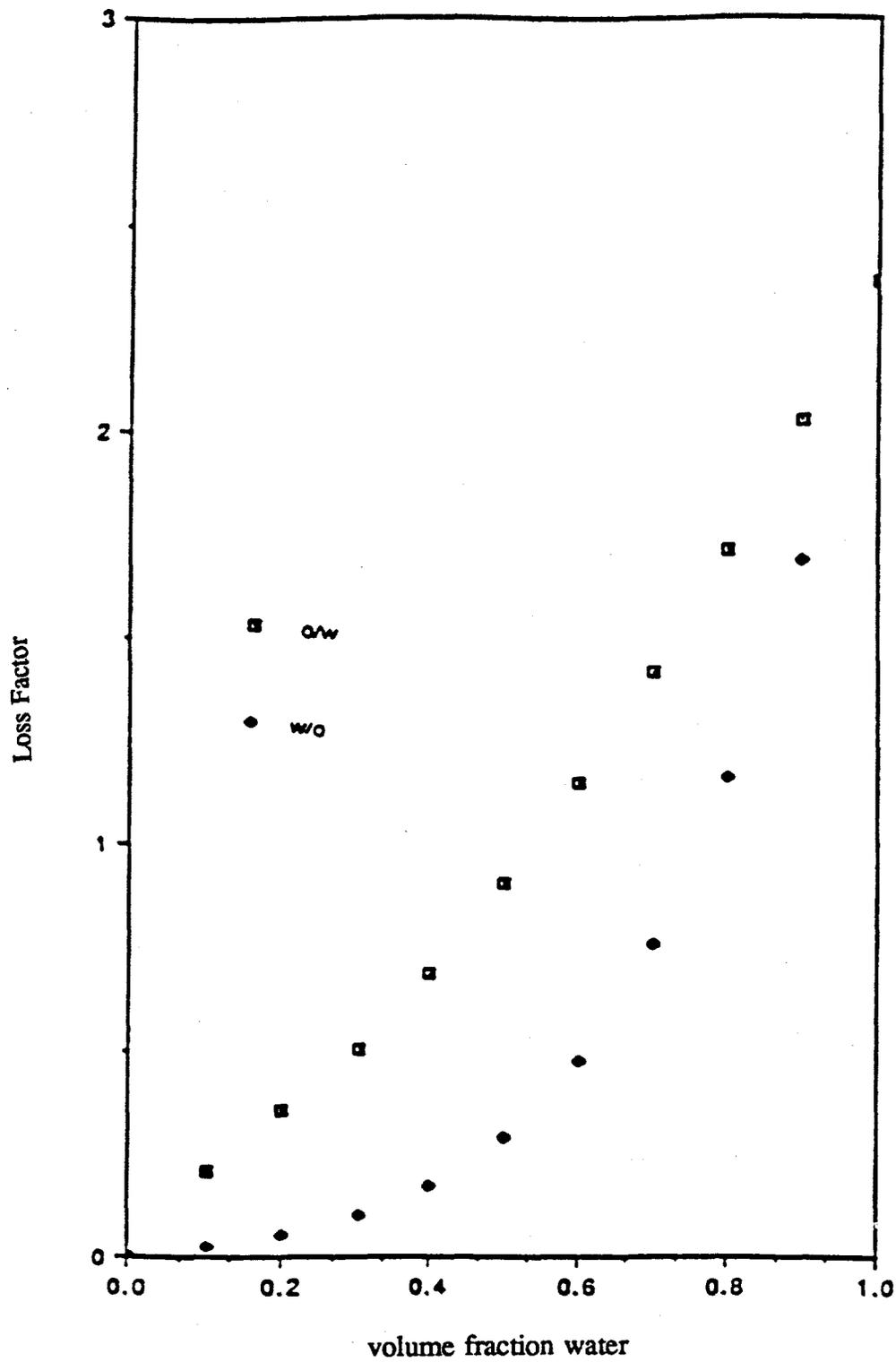


Figure 2. Computed Loss Factor values at 23.45 GHz for O/W and W/O emulsions inside Berea Sandstone core with a 20% porosity

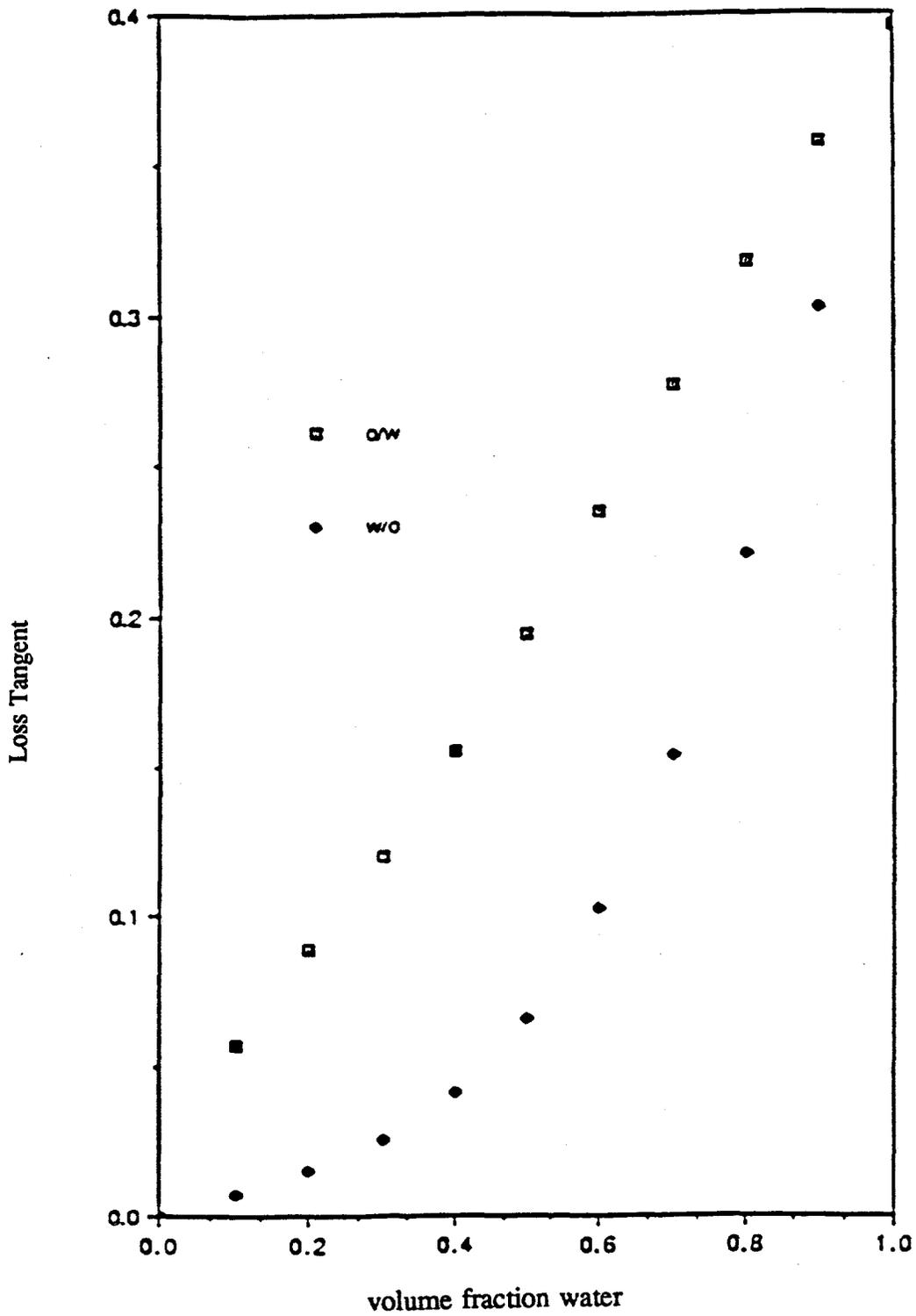


Figure 3. Computed Loss Tangent values at 23.45 GHz for O/W and W/O emulsions inside Berea Sandstone core with a 20% porosity

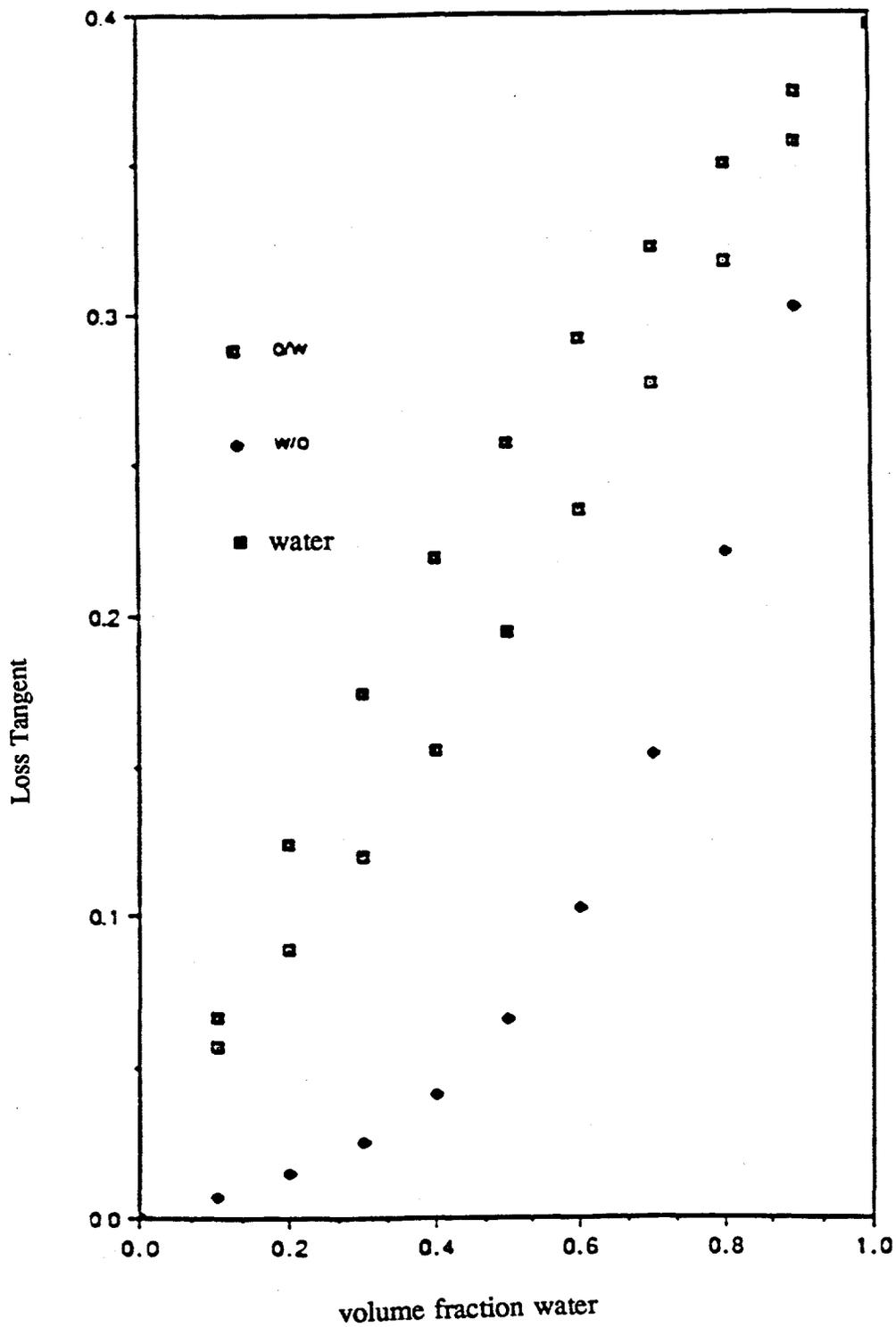


Figure 4. Computed Loss Tangent values at 23.45 GHz for Emulsified and Unemulsified Oil and Water Systems inside Berea Sandstone Core with a 20% Porosity

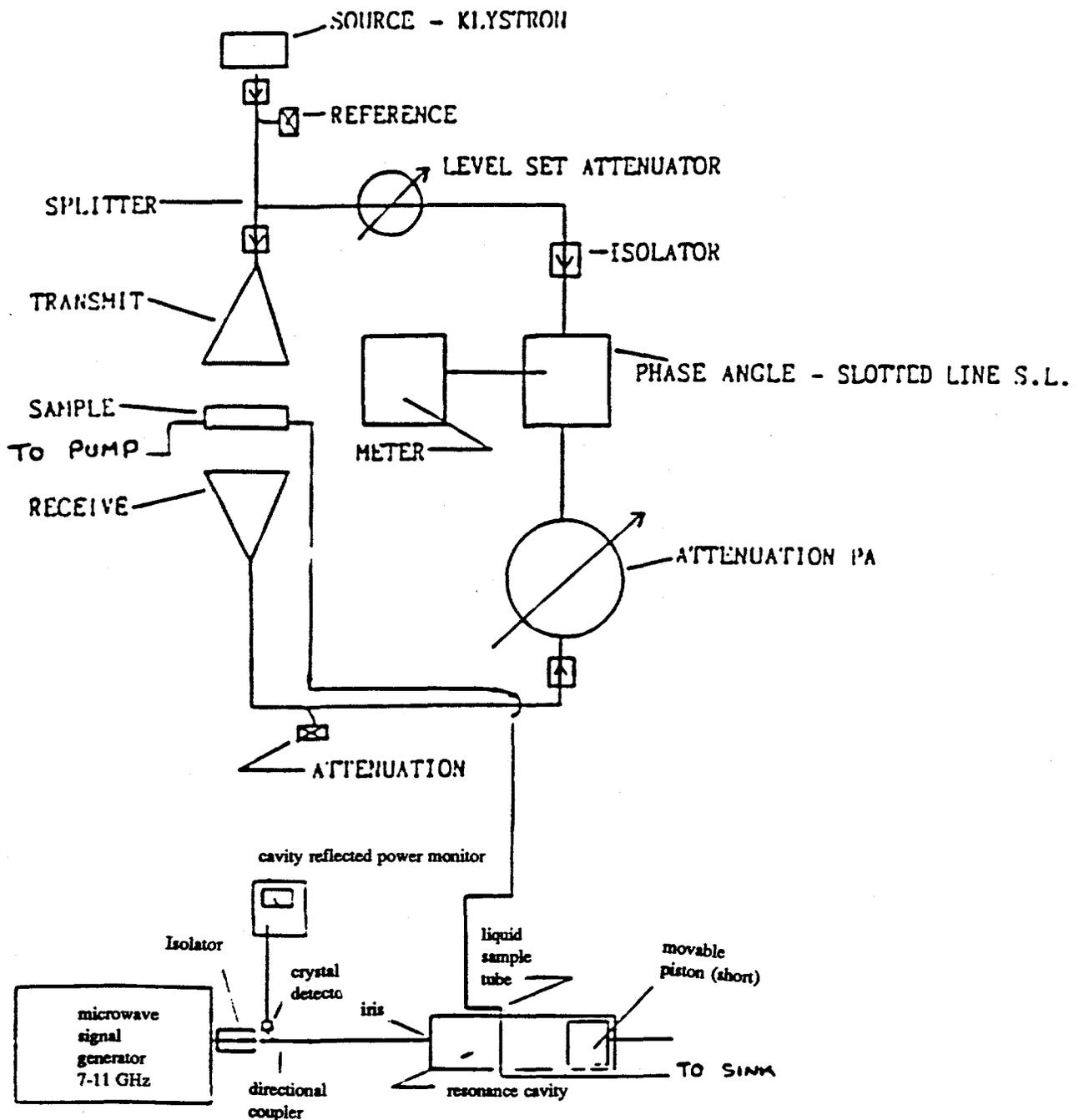


Figure 5. Schematic of Emulsion Core Flood Experiments with Emulsion Dielectric Behavior inside Porous Media Measured by Interference Dielectrometer at 23.45 GHz and the Effluent Concentration Monitored by a Cavity Resonance Dielectrometer

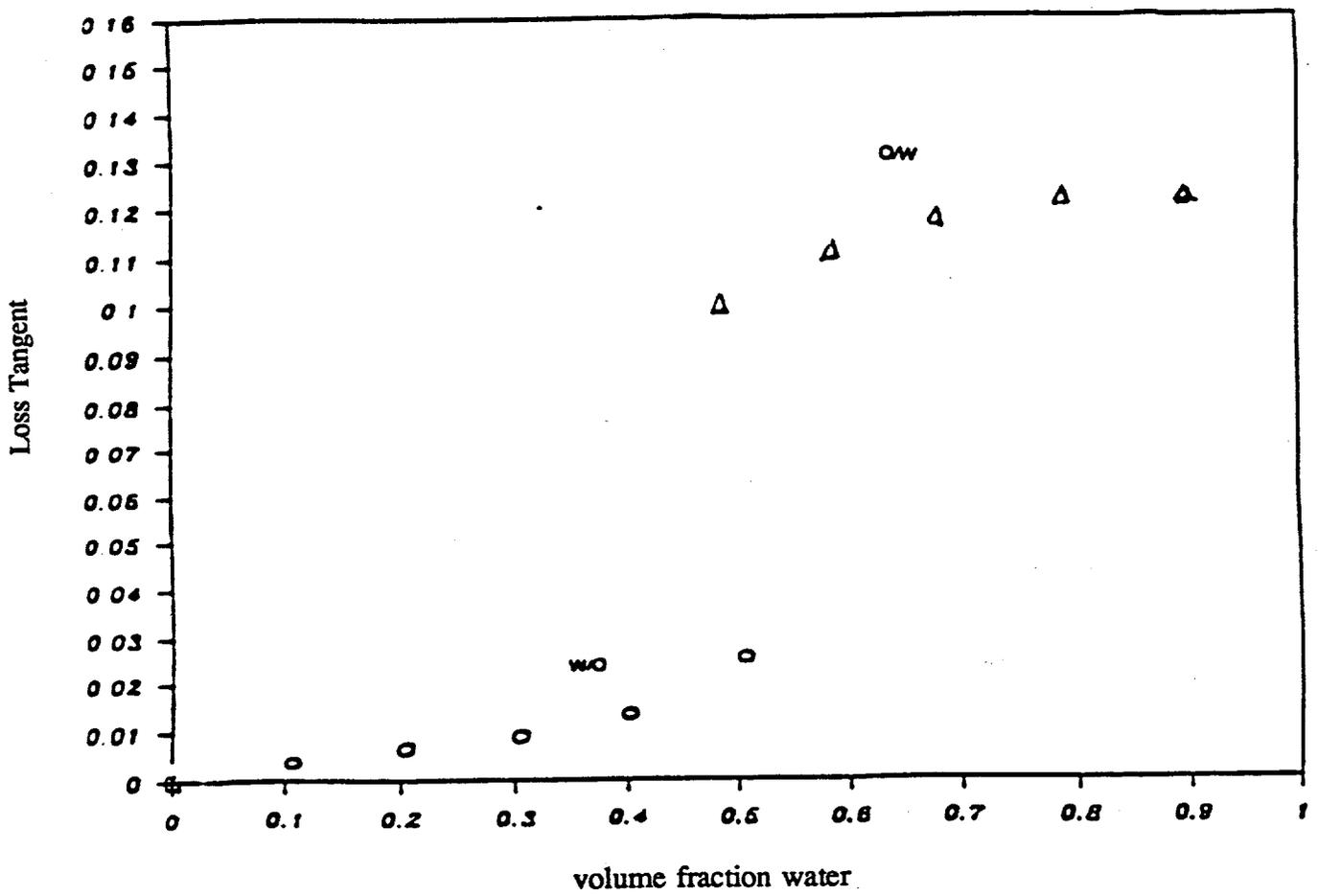


Figure 6. Experimentally Measured Loss Tangent Values at 23.45 GHz for Emulsions Inside porous Media at a 20% rock Porosity

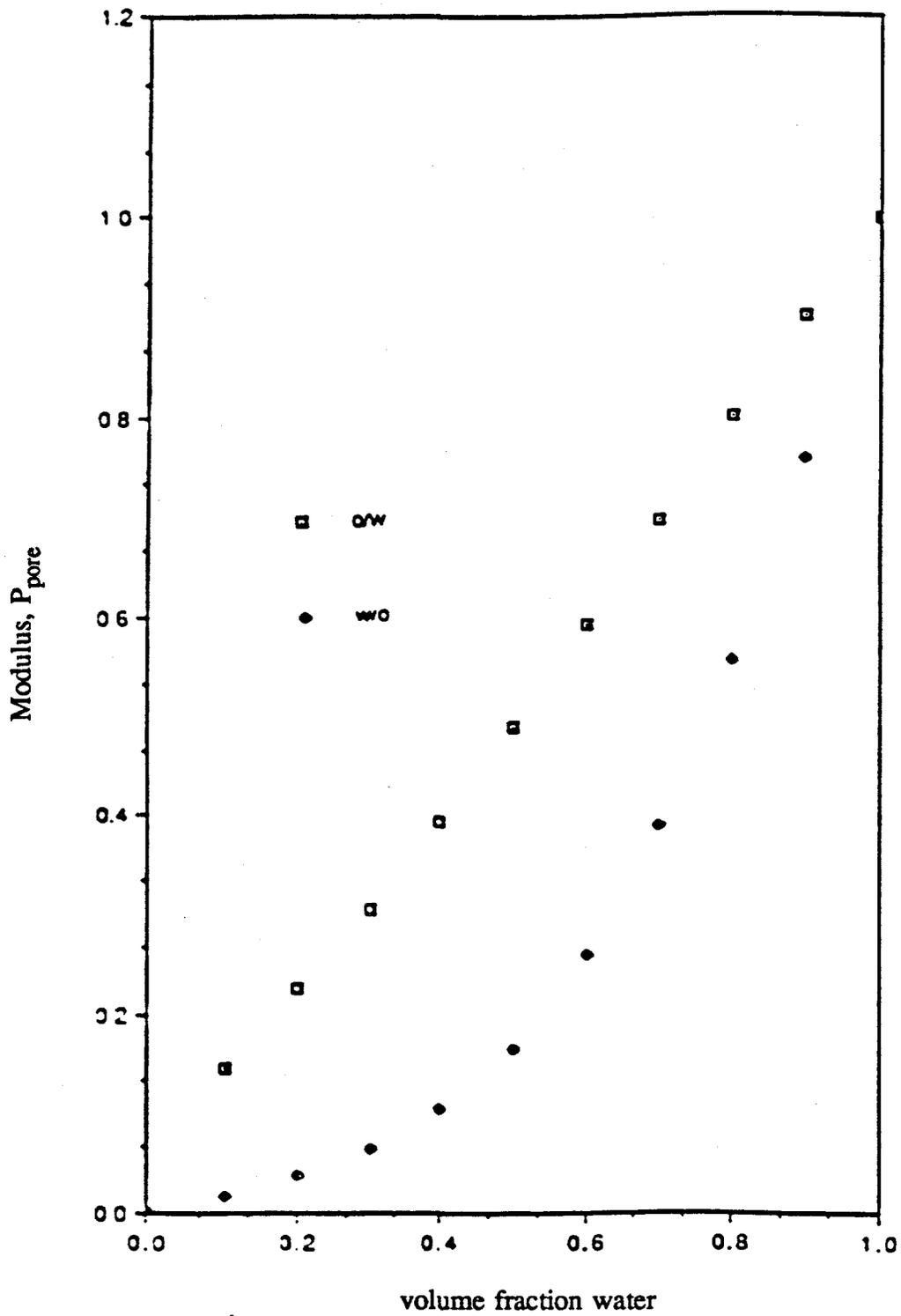


Figure 7. Computed Frequency Invariant Dielectric Modulus  $P_{\text{pore}}$  for O/W and W/O Emulsions inside Berea Sandstone Core with a 20% Porosity