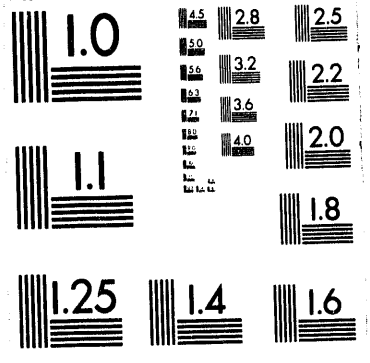
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IMPROVING RESERVOIR CONFORMANCE USING GELLED POLYMER SYSTEMS

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Objectives

The general objectives are to 1) to identify and develop gelled polymer systems which have potential to improve reservoir conformance of fluid displacement processes, 2) to determine the performance of these systems in bulk and in porous media, and 3) to develop methods to predict the capability of these systems to recover oil from petroleum reservoirs.

This work focuses on three types of gel systems - an aqueous polysaccharide (KUSP1) system that gels as a function of pH, the chromium(III)-polyacrylamide system and the aluminum citrate-polyacrylamide system. Laboratory research is directed at the fundamental understanding of the physics and chemistry of the gelation process in bulk form and in porous media. This knowledge will be used to develop conceptual and mathematical models of the gelation process. Mathematical models will then be extended to predict the performance of gelled polymer treatments in oil reservoirs.

Summary of Technical Progress

Task I : Development and Selection of Gelled Polymer Systems

I.1 Development of KUSP1 and Derivatives

Determination of the degree of polymerization of KUSP1 was accomplished previously by a modification of a colorimetric arsenomolybate method (Nelson, N., "A Photometric Adaption of the Somogyi Method for the Determination of Glucose," J. Biol. Chem., **153**, (1944) 375-380). This method was limited by the insolubility of KUSP1. An alternate method was identified for determination of the number of reducing groups on KUSP1 which is used to determine the degree of polymerization. This new method, which was developed for protein assays and employs the Pierce BCA reagent, can be performed at alkaline conditions where KUSP1 is soluble. This new method is now being used to re-examine the effects of growth conditions of *Cellulomonas flavigena* upon the synthesis of KUSP1, and further, to investigate whether alkaline extraction of the polymer from encapsulated cells results in chemical modification of KUSP1.

Task II : Physical and Chemical Characterization of Gel Systems

II.1 Rheological Characterization

A study of the effect of shear on the gelation of a polyacrylamide-chromium(III) system was initiated. The gel system was subjected to steady shear with a superimposed oscillatory shear on a Weissenberg rheometer. This parallel superposition experiment allows for the determination of the storage modulus (and other linear viscoelastic properties) concurrently with the shear viscosity.

Results of two experiments conducted at a net steady shear rate of 7.47 s^{-1} and at oscillatory frequency of 1.0 Hz and an oscillatory strain of 0.5 strain are shown in Figure 1. Included in Figure 1 are the moduli-time data for the same experiment using only oscillatory shear (zero steady shear). For the samples subjected to a steady shear of 7.47 sec^{-1}, the data appear curious but are reproducible. Application of steady shear significantly affects the gelation as characterized by the development of the

storage modulus (G') with time. Future plans include the acquisition of data at other selected steady shear rates and analyzing/interpreting the data.

Task III : Mechanisms of In Situ Gelation

Experiments were conducted to determine if fluid-rock interactions would reduce the pH of a KUSP1 solution to the extent to cause gelation. Two pore volumes of a solution containing 1.0% KUSP1, 0.1 N NaOH and 2.0% NaCl were flowed through a 1-foot long sandpack initially saturated with 0.1 N NaOH and 2.0% NaCl. Development of increased flow resistance in only the front section of the sandpack indicated a possible problem concerning the injectivity of KUSP1 solutions in porous matrix.

Small volumes of polymer solution that were injected subsequently into the sandpack showed that fluid-rock interactions had not triggered in situ gelation. Flow resistance in the sandpack as well as the pH of the effluent were unchanged after six and 21 days of shut-in time.

The experiment described above was repeated except the injected polymer solution was filtered through a 5.0 micron filter to determine if filtration would improve the injectivity of the polymer solution. Increased flow resistance in the first section of the sandpack was again observed but not to the extent that occurred when using the unfiltered solution. Work is in progress to improve the injectivity of KUSP1 solutions and to determine the effect of fluid-rock interactions using Berea sandstone cores.

Task IV : Mathematical Modelling of Gel Systems

IV.2 Develop of mathematical model(s) of laboratory in situ gelation

Fluid-rock interactions can play a key role in determining the efficacy of gelled polymer treatments. Effects of dissolution reactions and ion-exchange reactions were examined indivually by simulating core-flood experiments. A set of simulations was conducted to study the simultaneous effects of sodium/hydrogen ion exchange and silica dissolution on high pH brine solutions. These simulations correspond to core-flood experiments reported by Bunge and Radke ("Migration of Alkaline Pulses in Reservoir Sands", SPEJ, (Dec. 1982)) with a Huntington Beach Sand core at four different flow rates.

Figure 2 shows predicted profiles of the reduced hydroxide-ion concentration in the effluent compared to experimental results. The hydroxide-ion concentration is normalized by its injected value of 0.046 moles/liter. Simulated profiles show good agreement with the experimental data. As the flow rate is reduced, the contact time between the injected solution and the rock matrix is increased. The kinetic nature of the silica-dissolution reaction produces progressively larger drops in the hydroxide-ion concentration. Sodium/hydrogen ion-exchange results in a delay of about 2.5 PV before the breakthrough of the injected hydroxide concentrations. This delay is independent of the flow rate which suggests the validity of the assumption of local equilibrium for the ion-exchange reaction.

The physical parameters and reaction parameters characterizing the experiment were not known *a priori*. A set of typical parameters was adopted for the simulations and this set was used for all four simulations. The model describes all the essential features shown by experimental data. These results establish the validity of the assumptions in the proposed model and the underlying mechanisms for silica dissolution and sodium/hydrogen ion exchange.

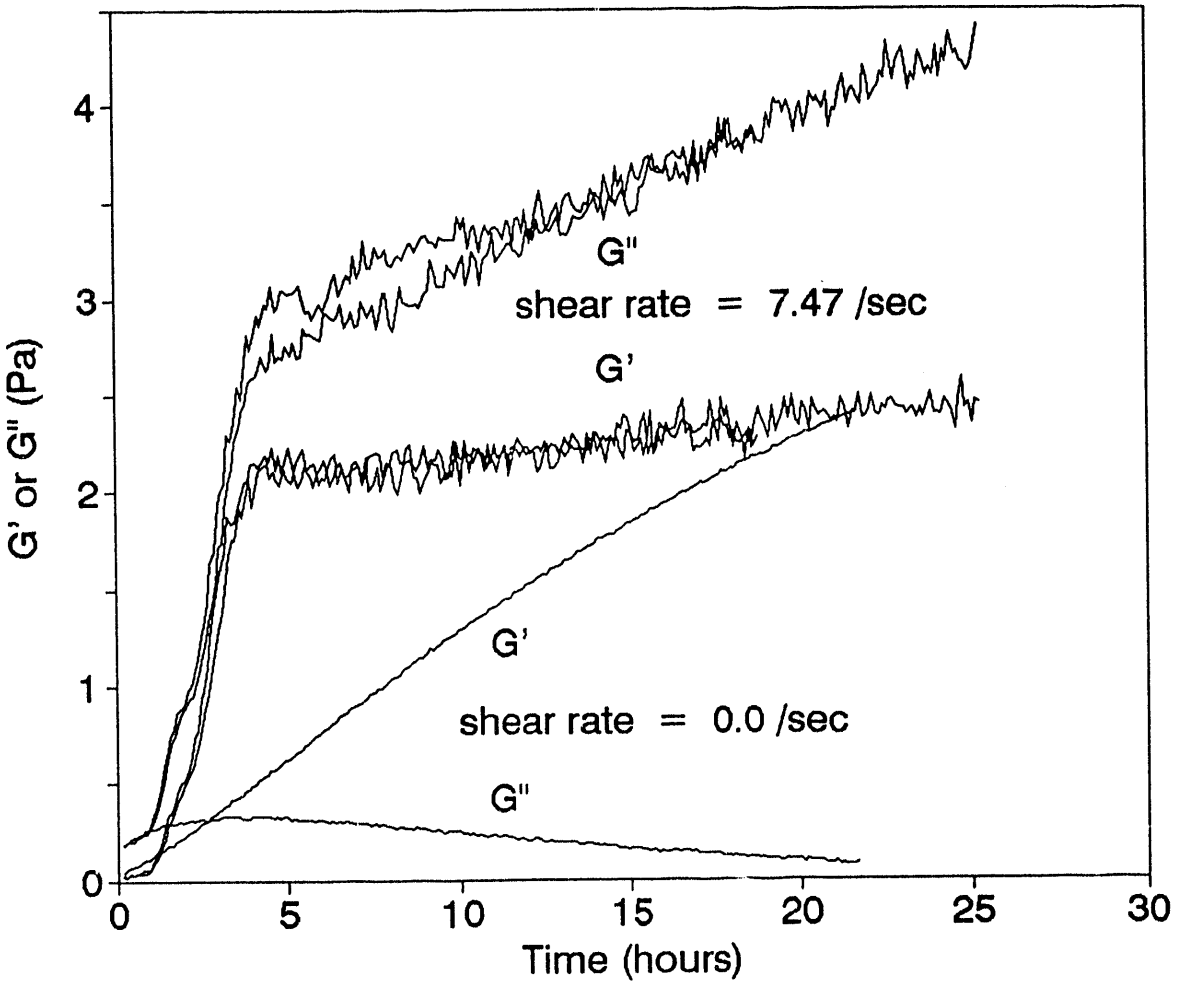

Figure 1 : Development of Storage Modulus and Loss Modulus with Time With and Without Steady Shear.

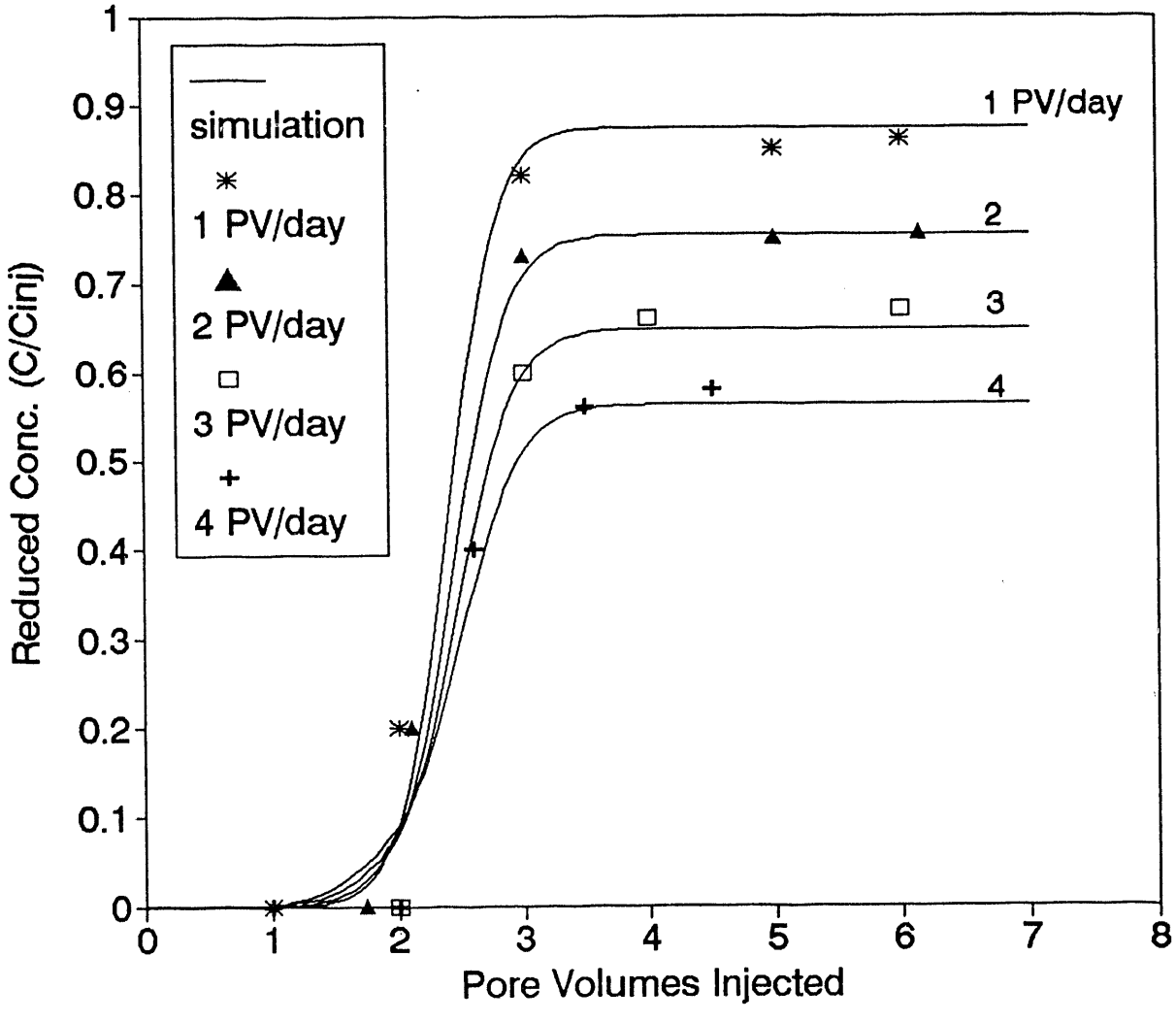

Figure 2 : Simulated Profiles of the Effluent Hydroxide Concentration Compared to Experimental Results of Bunge and Radke.

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