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DEVELOPMENT OF COST-EFFECTIVE SURFACTANT FLOODING TECHNOLOGY

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OBJECTIVES

The objective of this research is to develop cost-effective surfactant flooding technology by using simulation studies to evaluate and optimize alternative design strategies taking into account reservoir characteristics, process chemistry, and process design options such as horizontal wells. Task 1 is the development of an improved numerical method for our simulator that will enable us to solve a wider class of these difficult simulation problems accurately and affordably. Task 2 is the application of this simulator to the optimization of surfactant flooding to reduce its risk and cost.

SUMMARY OF TECHNICAL PROGRESS

In this quarter, we have continued working on Task 2 to optimize surfactant flooding design and have included economic analysis to the optimization process. An economic model was developed using a spreadsheet and the discounted cash flow (DCF) method of economic analysis. The model was designed specifically for a domestic onshore surfactant flood and has been used to economically evaluate previous work that used a technical approach to optimization. The DCF model outputs common economic decision making criteria, such as net present value (NPV), internal rate of return (IRR), and payback period.

Simulation results from UTCHEM for an array of different tertiary surfactant flooding designs were imported into the economic model, using annual production values, to determine the most economical design. One set of simulation results varied the amount of surfactant by holding the surfactant concentration constant while varying the number of pore volumes injected into the reservoir. The results of the optimization process are shown in Figure 1, using NPV as the decision making variable. This example is 40 acre five-spot with a horizontal injector and a vertical producer. The results are for one realization of a three-dimensional stochastic permeability field describing a light oil sandstone reservoir typical of fluvial deltas. The Dykstra-Parsons coefficient was 0.8. The dome shaped curve clearly indicates that the economics can be optimized based on the composition of surfactant injected. The results of DCF analysis on the optimum case are given in Table 1. The chemical cost is a significant part (53%) of the operating expense, not including royalty payments and taxes, which is why the economics are so sensitive to the surfactant flooding design.

The optimum case, determined by economic analyses, used a deterministic one-point analysis for a specified set of economic conditions. Realistically, it is not possible to predict future economic environments, so sensitivity analysis and risk analysis were performed on the optimum case. Sensitivity analysis on key economic variables, such as oil price, chemical prices, inflation, and operating cost was performed easily with the aid of tools provided in the spreadsheet package. The most important economic variables were found to be, in order of importance, oil price, operating cost, and chemical prices. Previous sensitivity studies on reservoir parameters and well arrangements were economically evaluated to determine which have the greatest impact on project economics. The results showed that different permeability field realizations significantly alter the economics and at current oil prices the use of horizontal injection wells is more profitable than vertical injection wells.

The uncertainty and risk associated with a surfactant flooding project was evaluated using a commercial spreadsheet add-on application that can directly access the economic model used in the optimization process. The most important economic variables were used as inputs for Monte Carlo simulation, which is one of the most comprehensive risk assessment techniques. Different probability distributions were used to define various degrees of uncertainty in the input variables. The simulation was run using 2000 iterations and the results are shown as a distribution of NPVs in Figure 2. This result illustrates the likely distribution of outcomes for 2000 realizations of a surfactant flooding project of identical design. This relatively favorable result is based upon a highly effective synthetic surfactant that is available commercially in large quantities for about $1 per pound. Similar surfactants have been successfully used in field tests but cost 2 to 3 times as much to manufacture. This lower surfactant cost plus the optimization work done using UTCHEM explain most of the difference between these results and many other less favorable estimates in the literature. Of course, these results depend very strongly on the reservoir and other factors as well. Additional analysis of other cases will be reported later.

Table 1: Results of DCF analysis for the optimum surfactant flooding case

Variable	Value
Internal Rate of Return (IRR)	18.40%
Net Present Value (NPV)	$1,750,115
Discounted Return on Investment (DROI)	0.39
Growth Rate of Return (GROR)	14.78%
Payback Period (yrs)	5.57
Discounted Payback Period (yrs)	6.39
Revenue ($/bbl oil produced)	$18.00
Royalty ($/bbl oil produced)	$2.25
Capital Cost ($/bbl oil produced)	$0.06
Operating Cost ($/bbl oil produced)	$4.62
Chemical Cost ($/bbl oil produced)	$5.19
Taxes ($/bbl oil produced)	$2.34
Profit ($/bbl oil produced)	$3.54

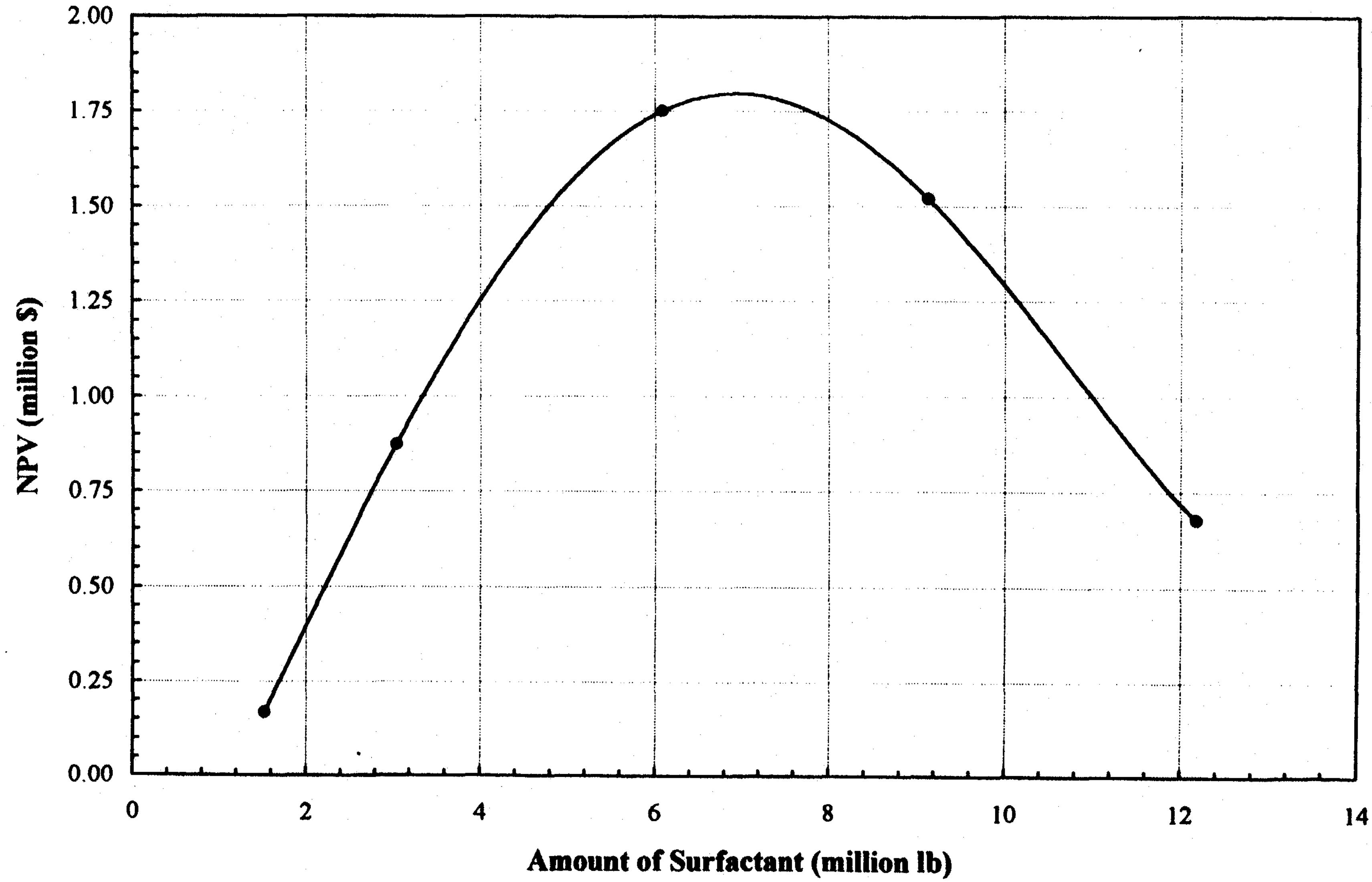

Fig. 1 **Optimization of surfactant at a concentration of 0.50 vol. % using discounted cash flow analysis.**

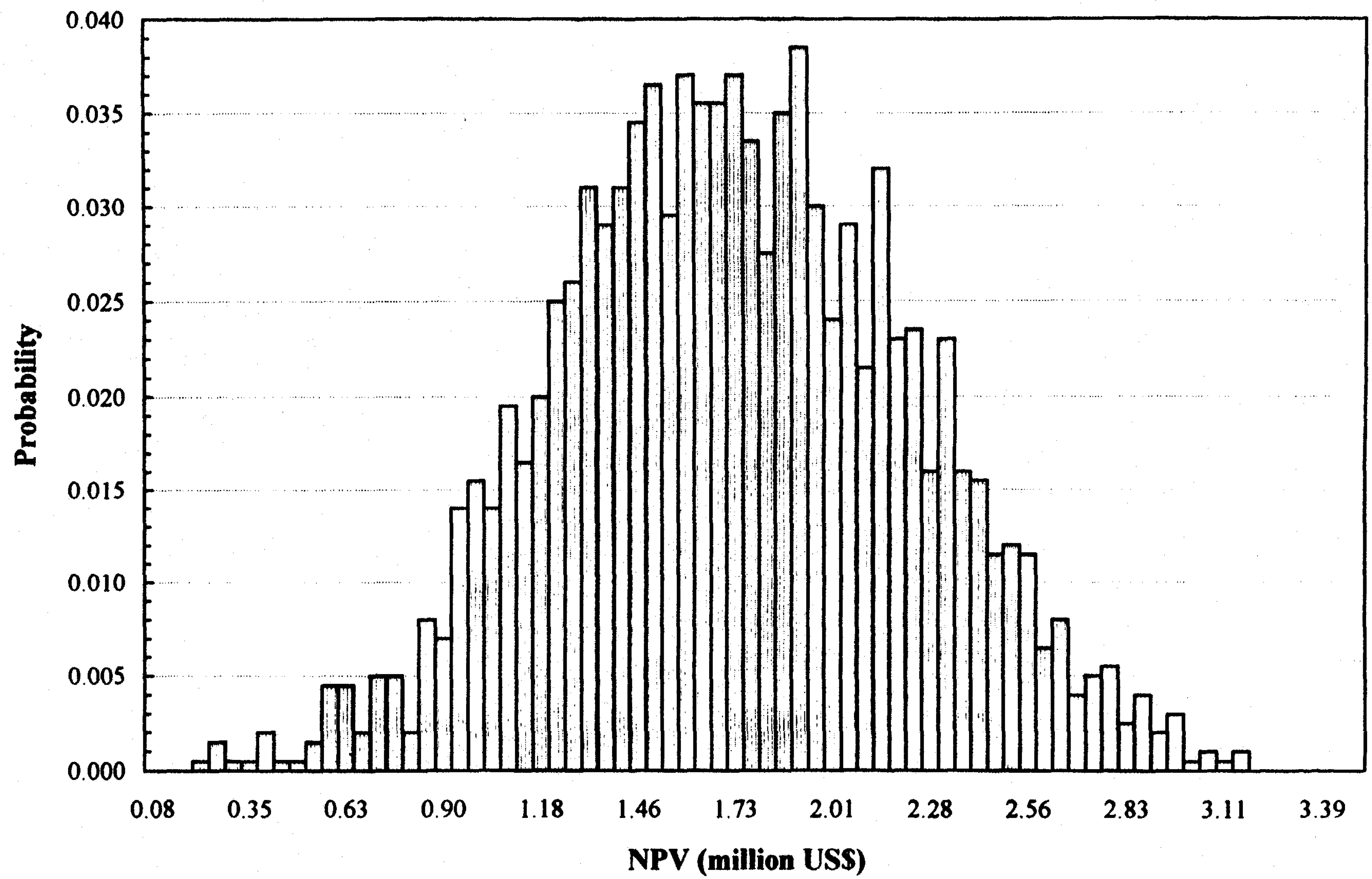

Fig. 2 NPV distribution from a Monte Carlo simulation.