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Simulation of 1/8 Five-/Nine-Spot Patterns

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Simulation of complex recovery processes often is performed using a single pattern, which may be a five-, seven-, or nine-spot. This approximation of a total-field multiple-pattern development by a representative pattern significantly reduces computing time and cost. This Forum is limited to a single pattern in a network of repeated five- or nine-spot patterns in an areally homogeneous formation. The formation may have arbitrary vertical heterogeneity and any number of layers. The single pattern contains two wells in the five-spot case and four wells in the nine-spot case. The four sides of the square pattern are no-flow or insulated boundaries.

The single-pattern simulation should be performed for the smallest symmetrical element of the pattern to minimize computing cost. This well-known element is one-eighth of a pattern. Nevertheless, simulations of one-half and one-fourth pattern elements with areal homogeneity and square (uniform) grid blocks continue in practice and occasionally appear in the literature. Owing to symmetry within the pattern, the pressure (and saturation, composition, etc.) distribution within the one-eighth element defines the distribution throughout the pattern.

Transmissibility and block PV alterations necessary for exact reproduction of five- or nine-spot results by a one-eighth pattern calculation are well-known for the five-point difference scheme and are omitted here. This Forum describes a simple alteration necessary for identity of one-half or one-fourth pattern and one-eighth pattern results using the nine-point difference scheme[1] with either parallel or diagonal grids.[2]

Figs. 1a and 1b show parallel and diagonal, uniform block-centered grids for the five- or nine-spot. The wells marked by an empty circle are absent in the five-spot. The x- and y- directions and (nine-point) diagonal transmissibilities discussed in detail by Yanosik and McCracken[1] are noted on Fig. 1a by the symbols x, y and d, respectively. Let the normal five-point scheme x- or y-direction transmissibility associated with Grids 1a and 1b be normalized to 1.0. For the nine-point scheme, then, the x- and y-direction transmissibilities are two-thirds and the diagonal transmissibilities are one-sixth.[1] Because of the half-blocks along the horizontal (vertical) edges, the nine-point $x(y)$-direction transmissibilities along these edges are one-half of two-thirds or one-third. For the one-eighth pattern cases, the nine-point diagonal transmissibilities along the 45° triangle sides must be halved. This one-half factor is necessary simply because the 45° triangular boundary is a streamline. However, all internal nine-point $x(y)$-direction transmissibilities must

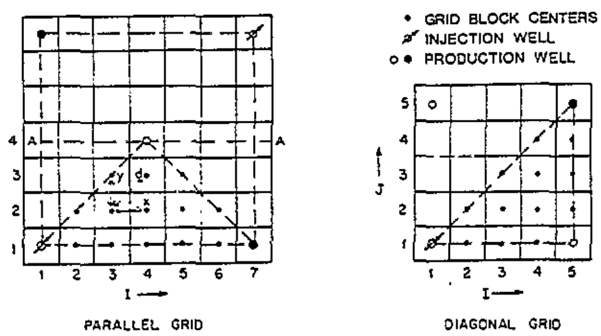

Fig. 1—Five- or nine- spot pattern grids.

remain equal to two-thirds. Obviously, all diagonal or $x(y)$-direction transmissibilities connected to blocks outside the one-eighth pattern grid are zero.

This identity of one-eighth and full-pattern nine-point simulations is not limited to the uniform grids shown. For the diagonal grid, any $N \times N$ grid with variable $\Delta x(\mathrm{I})$, $\Delta y(\mathrm{J})$ can be used provided $\Delta y(\mathrm{J}) = \Delta x(\mathrm{I})$ for each $\mathrm{I}=\mathrm{J}$. For the parallel grid, any $N \times N$ grid (on a one-half pattern basis) suffices, provided that $\Delta y(\mathrm{J}) = \Delta x(\mathrm{I})$ for each $\mathrm{I}=\mathrm{J}$ and that the $\Delta y(\mathrm{J})$ are symmetrical about A-A. Again, the only requirement for identity of nine-point one-eighth and full-pattern simulations is halving the normal diagonal transmissibilities along the 45° edges in the one-eighth pattern case.

For the square one-half and one-fourth pattern elements, use of the one-eighth pattern element reduces computing time by factors of roughly four and two, respectively. Thus, the importance of simulating the triangular elements is obvious. These ratios can be larger if direct solution is used since matrix bandwidth increases from the one-eighth to one-fourth or one-half pattern simulations and direct solution time is roughly proportional to the square of bandwidth.

References

1. Yanosik, J.L. and McCracken, T.A.: "A Nine-Point, Finite-Difference Reservoir Simulator for Realistic Prediction of Adverse Mobility Ratio Displacements," *Soc. Pet. Eng. J.* (Aug. 1979) 253–62.
2. Todd, M.R., O'Dell, P.M., and Hirasaki, G.J.: "Methods for Increased Accuracy in Numerical Reservoir Simulators," *Soc. Pet. Eng. J.* (Dec. 1972) 515–30.

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(on a 1/2 pattern basis) suffices, provided $\Delta y(J) = \Delta x(I)$ for each $I=J$, and the $\Delta y(J)$ are symmetrical about A-A. Again, the only requirement for identity of nine-point 1/8 and full pattern simulations is halving the normal diagonal transmissibilities along the 45 degree edges in the 1/8 pattern case.

For the square 1/2 5-spot and 1/4 9-spot elements, use of the 1/8 pattern element reduces computing time by factors of roughly 4 and 2, respectively. Thus, the importance of simulating the triangular elements is obvious. These ratios can be larger if direct solution is used since matrix band width increases from the 1/8 to 1/4 or 1/2 pattern simulations and direct solution time is roughly proportional to the square of band width.

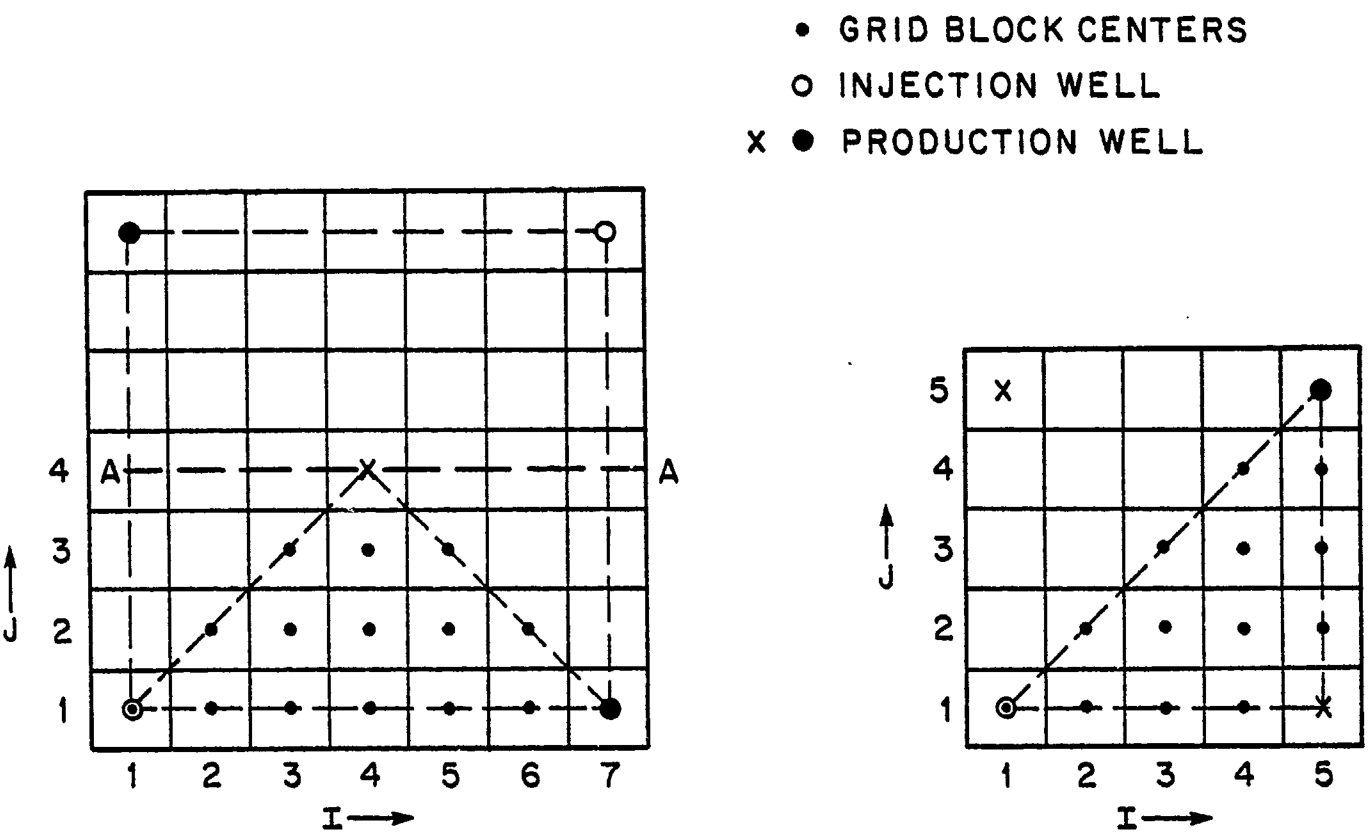
REFERENCES

1. Yanosik, J.L., and McCracken, T.A., "A Nine-Point, Finite-Difference Reservoir Simulator for Realistic Prediction of Adverse Mobility Ratio Displacements," Soc. Pet. Eng. J. (Aug., 1979), 253-262.

2. Todd, M.R., O'Dell, P.M. and Hirasaki, G.J.: "Methods for Increased Accuracy in Numerical Reservoir Simulators," Soc. Pet. Engr. J. (Dec., 1972) 515.

FIGURE 1
PATTERN GRIDS

5-SPOT OR 9-SPOT



1A. PARALLEL GRID

1B. DIAGONAL GRID