A five-spot waterflood process as applied to the digital computer based on the Prats technique

Leonard Koederitz

Follow this and additional works at: http://scholarsmine.mst.edu/masters_theses

Department: Geosciences and Geological and Petroleum Engineering

Recommended Citation

This Thesis - Open Access is brought to you for free and open access by the Student Research & Creative Works at Scholars' Mine. It has been accepted for inclusion in Masters Theses by an authorized administrator of Scholars' Mine. For more information, please contact weaverjr@mst.edu.
A FIVE-SPOT WATERFLOOD PROCESS AS APPLIED
TO THE DIGITAL COMPUTER BASED ON THE PRATS TECHNIQUE

BY

LEONARD FREDERICK KOEDERITZ

A

THESIS

submitted to the faculty of

UNIVERSITY OF MISSOURI-ROLLA

in partial fulfillment of the requirements for the

Degree of

MASTER OF SCIENCE IN PETROLEUM ENGINEERING

Rolla, Missouri

1969

Approved by

(advisor)

[Signatures]
ABSTRACT

The technique for the prediction of injection rates and production history of a five-spot secondary recovery field pattern as presented by Prats has been significantly modified to permit rapid and accurate digital applications eliminating the heretofore prohibitive reliance upon electrolytic model results for intermediate data values following water front breakthrough.
ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. R. E. Carlile, Professor J. P. Govier, and Professor T. C. Wilson of the Petroleum Engineering Department of the University of Missouri-Rolla for their suggestions and guidance throughout the development of this investigation. Grateful appreciation is also extended to the Gulf Oil Corporation under whose fellowship this work was performed.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>i</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>ii</td>
</tr>
<tr>
<td>LIST OF ILLUSTRATIONS</td>
<td>iv</td>
</tr>
<tr>
<td>I.  INTRODUCTION AND LITERATURE REVIEW</td>
<td>1</td>
</tr>
<tr>
<td>II. DISCUSSION</td>
<td>4</td>
</tr>
<tr>
<td>III. INTERPRETATION OF THE PROGRAM</td>
<td>15</td>
</tr>
<tr>
<td>IV. SAMPLE CALCULATIONAL PROCEDURE</td>
<td>16</td>
</tr>
<tr>
<td>V. RESULTS</td>
<td>18</td>
</tr>
<tr>
<td>VI. CONCLUSIONS</td>
<td>25</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>26</td>
</tr>
<tr>
<td>APPENDIX</td>
<td>27</td>
</tr>
<tr>
<td>NOMENCLATURE</td>
<td>28</td>
</tr>
<tr>
<td>COMPUTER PROGRAM</td>
<td>30</td>
</tr>
<tr>
<td>FLOW CHART (Located in Packet)</td>
<td>35</td>
</tr>
<tr>
<td>VITA</td>
<td>45</td>
</tr>
</tbody>
</table>
# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Figure No.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>Pictorial Five-Spot Waterflood History</td>
<td>2</td>
</tr>
<tr>
<td>II.</td>
<td>Dimensionless Injectivity as a Function of Cumulative Water Injection (Schematic)</td>
<td>5</td>
</tr>
<tr>
<td>III.</td>
<td>Diagrammatic Five-Spot Waterflood During Period 3A</td>
<td>6</td>
</tr>
<tr>
<td>IV.</td>
<td>Per Cent Deviation as a Function of Oil Fraction</td>
<td>19</td>
</tr>
<tr>
<td>V.</td>
<td>Per Cent Deviation as a Function of Gas Fraction</td>
<td>20</td>
</tr>
</tbody>
</table>
I. INTRODUCTION AND LITERATURE REVIEW

M. Prats and colleagues have presented an approach to the prediction of flood rates on a five-spot well pattern by assuming that the reservoir consists of several distinct layers, each of which has a uniform permeability; however, this approach requires an electrolytic model for the determination of rates after water breakthrough has occurred. The technique is not explicitly defined from oil breakthrough to water front interference. The purpose of this paper is to provide an alternate method of solution from the time of oil breakthrough until production has ceased.

Originally, the technique divided production history into three periods, with the third or final production period subsequently subdivided into two production cycles, as noted in Figure I. The first period, from the beginning of injection until oil bank interference occurs, is treated as a dual radial flow system, both of which employ a Darcy's Law solution. Period 2, from oil bank interference until oil breakthrough, is also solved with the aid of Darcy's Law. From the time of oil breakthrough until interference of the advancing water fronts occurs, Period 3A, performance has been simulated by the use of Darcy's Law, with an assumed radial flow. After water breakthrough, however, during Period 3B, the performance is determined through the use of a least squares fit of a fourth degree polynomial to express the dimensionless injectivity, and which serves to replace
FIGURE I. - PICTORIAL FIVE-SPOT WATERFLOOD HISTORY

Period 1:

Period 2:

Period 3A:

Period 3B:

Legend

- Water Bank
- Gas Region
- Oil Bank
- Injection Well
- Production Well
the electrolytic model necessity for rate determination. This solution does not require a knowledge of either pressures or time elapsed in order to determine the production history; however, knowledge of either one will allow the remaining variable to be calculated at any point in the history. This is accomplished through the considerations of the definition of dimensionless injectivity, and the assumption that Darcy's Law is valid.
II. DISCUSSION

The solutions involved in Periods 1 and 2 are explained thoroughly in the original manuscript of Prats et. al.; therefore, an explanation of the equations employed would be redundant and unprofitable. Having derived the necessary equations for the above-mentioned periods, it is sufficient to note that they have been applied in their original form, with no pertinent modifications. In the Prats' technique, it states that, for the period from oil breakthrough to water breakthrough (Period 3A), a very good approximation of the true variation of performance with cumulative injection in this region may be obtained by sketching, from the point of oil breakthrough, a curve having slight slope, which joins smoothly with the point of water breakthrough, as indicated in Figure II. It should be noted that water bank interference and water breakthrough occur almost simultaneously. Accordingly, the principle modifications of this work are vested in Periods 3A and 3B.

Period 3A:

During the time from oil breakthrough until water front interference one may assume that water is the phase undergoing interference, and that both oil and water flow radially from a water-oil front located at some radius of the oil region around the producing well, as indicated in Figure III, which shall be referred to as the quasi- or pseudo-radius.
FIGURE II. DIMENSIONLESS INJECTIVITY AS A FUNCTION OF CUMULATIVE WATER INJECTION (SCHEMATIC)

$Id = \text{Dimensionless Injectivity}$

$W_{id} = \text{Cumulative Injection}$

- **A** = End of Period 1 (Oil Bank Interference)
- **B** = End of Period 2 (Oil Breakthrough)
- **C** = End of Period 3A (Water Breakthrough)
FIGURE III. DIAGRAMMATIC FIVE-SPOT WATERFLOOD DURING PERIOD 3A

Legend
- Injection Well
- Production Well
Employing the electrolytically-derived equation for flow under interference to the water phase, we obtain

$$Q_w = \frac{\pi k_w h (P_w - P_L)}{\mu_w (\ln \frac{L}{r_w} - 0.964)} \quad \text{(1)}$$

and, making use of Darcy's Law for the radially flowing portions, we also get

$$Q_w = \frac{2\pi k_w h (P_4 - P_L)}{\mu_w \ln \frac{r_4}{r_w}} \quad \text{(2)}$$

for the water phase, and

$$Q_o = \frac{2\pi k_o h (P_4 - P_L)}{\mu_o \ln \frac{r_4}{r_w}} \quad \text{(3)}$$

for the oil phase. The respective pressure differentials may be obtained as follows:

$$P_w - P_L = Q_w \mu_w (\ln \frac{L}{r_w} - 0.964) / \pi k_w h \quad \text{(1A)}$$

$$P_4 - P_L = Q_w \mu_w \ln \frac{r_4}{r_w} / 2\pi k_w h \quad \text{(2A)}$$

$$P_4 - P_L = Q_o \mu_o \ln \frac{r_4}{r_w} / 2\pi k_o h \quad \text{(3A)}$$

* Nomenclature given in Appendix.
The total pressure drop may be found by combining Equations (1A), (2A), and (3A) yielding

\[ P_w - P_L = \Delta P = (P_w - P_L)_0 \text{ int.} - (P_4 - P_L)_w + (P_4 - P_L)_o. \]  

(4)

Now that we have the total \( \Delta P \) expressed, we can define a dimensionless injectivity applicable to Period 3A as

\[ I_D = \frac{Q_w \mu_w}{\Delta P k_w h}, \]  

(5)

and the pressure drop is found to be

\[ \Delta P = \frac{Q_w \mu_w}{\frac{Q_w \mu_w (\ln \frac{L}{r_w} - .964)}{\pi k_w h}} - \frac{Q_w \mu_w \ln \frac{r_4}{r_w}}{2\pi k_w h} + \frac{Q_o \mu_o \ln \frac{r_4}{r_w}}{2\pi k_o h}. \]  

(6)

However, since \( Q_w = Q_o \), the pressure drop becomes

\[ \Delta P = \frac{Q_w \mu_w (\ln \frac{L}{r_w} - .964)}{\pi k_w h} - \frac{Q_w \mu_w \ln \frac{r_4}{r_w}}{2\pi k_w h} + \frac{Q_w \mu_o \ln \frac{r_4}{r_w}}{2\pi k_o h}, \]  

(6A)

which may be solved for the reciprocal dimensionless injectivity as

\[ \frac{1}{I_D} = \left[ \frac{\mu_w (\ln \frac{L}{r_w} - .964)}{\pi k_w h} - \frac{\mu_w \ln \frac{r_4}{r_w}}{2\pi k_w h} + \frac{\mu_o \ln \frac{r_4}{r_w}}{2\pi k_o h} \right] (k_w h/\mu_w), \]  

(7)

and simplified to
By defining the water-oil mobility, $M_{w,o}$, as

$$M_{w,o} = \frac{k_w \mu_o}{k_o \mu_w},$$

and substituting in Equation (7A) yields:

$$\frac{1}{I_D} = \frac{2 \ln \frac{L}{r_w} - .964}{2\pi} - \frac{\ln \frac{r_u}{r_w}}{2\pi} + \frac{\ln \frac{r_u}{r_w}}{2\pi} M_{w,o} \tag{7B}$$

and, solving for dimensionless injectivity, we obtain

$$I_D = \frac{\ln \frac{L}{r_w} - .964 - \ln \frac{r_u}{r_w} + M_{w,o} \ln \frac{r_u}{r_w}}{2\pi} \tag{9}$$

which may be simplified to

$$I_D = \frac{2\pi}{2(\ln \frac{L}{r_w} - .964) + (M_{w,o} - 1) \ln \frac{r_u}{r_w}} \tag{9A}$$

Equation (9A) represents the dimensionless injectivity from oil breakthrough until water front interference. It is now necessary to determine the appropriate values of the quasi-radius, $r_u$, employed in Equation (9A). Referring to Figure III, the oil volume swept from $r_w$ to $r_u$, for a point source, is
\[(L^2 \phi - \pi r_w^2 \phi) S_o - (L^2 \phi h - \pi r_4^2 \phi h - \pi r_w^2 \phi h) S_{or} \]

\[+ \pi r_4^2 \phi h (S_o + S_g - S_{gr}) \],

(10)

which may be rearranged to yield

\[\phi h \pi r_w^2 (S_{or} - S_o) + L^2 \phi h S_o - (L^2 \phi h - \pi r_4^2 \phi h) S_{or} \]

\[+ \pi h \phi r_4^2 (S_o + S_g - S_{gr}) \].

(10A)

The last term in Equation (10A) indicates the amount of oil which has displaced gas and still remains to be produced. The amount of water injected into the reservoir may be expressed in terms of the volumes of oil and gas produced from oil to water breakthrough as,

\[(L^2 \phi h - \phi h \pi r_4^2 - \phi h \pi r_w^2) (S_o + S_g - S_{or} - S_{gr}) + \pi h \phi r_4^2 (S_g - S_{gr}) \],

(11)

which may be rewritten in the form

\[\phi h \pi r_w^2 (S_{gr} + S_{or} - S_g S_o) + (L^2 \phi h - \phi h \pi r_4^2) (S_o + S_g - S_{gr} - S_{or}) \]

\[+ \pi h \phi r_4^2 (S_g - S_{gr}) \].

(11A)

Since the quantity of water injected must be equivalent to the quantity of oil and gas removed, due to our assumption of one-to-one displacements, we can say that,
\[ \phi h \pi r_w^2 (S_{or} - S_o) + L^2 \phi h S_o - (L^2 \phi h - \pi r_4^2 \phi h) S_{or} + \pi h \phi r_4^2 S_o \]

\[ + \pi h \phi r_4^2 (S_{g - gr}) = \phi h \pi r_w^2 (S_{gr} + S_{or} - S_{g - S_o}) \]

\[ + (L^2 \phi h - \phi h \pi r_4^2) (S_o + S_{g - gr} - S_{or}) + \pi h \phi r_4^2 (S_{g - S_{gr}}). \quad (12) \]

Cancelling like terms, Equation (12) becomes

\[ L^2 \phi h S_o - (L^2 \phi h - \pi r_4^2 \phi h) S_{or} + \pi h \phi r_4^2 S_o \]

\[ = \phi h \pi r_w^2 (S_{gr} - S_g) + (L^2 \phi h - \phi h \pi r_4^2) (S_o + S_{g - gr} - S_{or}). \quad (13) \]

However, it may be shown that, in view of the magnitudes employed,

\[ \phi h \pi r_w^2 (S_{gr} - S_g) = 0 \quad (14) \]

resulting in

\[ L^2 \phi h S_o - (L^2 \phi h - \pi r_4^2 \phi h) S_{or} + \pi h \phi r_4^2 S_o \]

\[ = (L^2 \phi h - \phi h \pi r_4^2) (S_o + S_{g - gr} - S_{or}). \quad (15) \]

Defining WiD as cumulative injection per floodable five-spot pore volume, (with an assumed sweep efficiency of 100%),

\[ WiD = \frac{L^2 \phi h - \phi h \pi r_4^2}{L^2 \phi h}, \quad (16) \]

we may divide Equation (15) by the total pore volume and apply the definition of cumulative injection to yield
However, since the only water phase available is connate water,

\[ S_0 + S_g = 1 - S_{wc} \]  \hspace{1cm} (18)

Applying Equation (18) and cancelling similar terms yields

\[ S_0 - \frac{\phi h \pi r_4^2 S_0}{\phi h L^2} = W_{iD} (1 - S_{wc} - S_{gr}) \] \hspace{1cm} (19)

However, returning to one of the basic assumptions that all of the gas is removed from the reservoir, it can be assumed that

\[ S_{gr} = 0 \] \hspace{1cm} (20)

tyielding

\[ S_0 - \frac{\phi h \pi r_4^2 S_0}{\phi h L^2} = W_{iD} (1 - S_{wc}) \] \hspace{1cm} (21)

which may be solved for \( r_4^2 \) as:

\[ r_4^2 = \frac{L^2}{\pi} \left[ 1 - \frac{(1 - S_{wc}) W_{iD}}{S_0} \right] \] \hspace{1cm} (22)

In Equation (22), \( r_4 \) is the pseudo-radius of the oil bank existing in the reservoir between oil breakthrough at the production well and water bank interference in the reservoir as described in Figure III.
The value of cumulative injection at water breakthrough which is the terminal point of this approximation is determined from the sweep efficiency at that time of water breakthrough, which is a function of the water-oil mobility and the displacement factor, \( F \), which we define as

\[
F = 1 + \frac{S_o - S_{or}}{S_g - S_{gr}}.
\]

(23)

Period 3B:

After water breakthrough at the producing well, it has been found that a fourth order polynomial equation will approximate the dimensionless injectivity for water and oil flow as a function of the water cut at the producing well. The water cut has been approximated, in this technique, in a subroutine, by a third order polynomial which correlates the cut accordingly. For other examples, a determination of the water cut as a function of the amount of water injected and/or the mobility ratio may readily and easily be substituted into the computational scheme. The fractions of oil, water, and gas present at any given injectivity for each layer of permeability are then calculated according to the method employed in the original manuscript with the exception that, since the oil and gas fractions are normalized, the water fraction is assumed to be

\[
f_w = 1 - (f_o + f_g).
\]

(24)
If it is desired to calculate the time elapsed corresponding to the fractions present, a graphical technique may be applied at this point.
III. INTERPRETATION OF THE PROGRAM

The computational scheme employed by the program requires the following input parameters:

1) parameters initially employed by the original technique (located in subroutine VALU);

2) values of the cumulative water injection in terms of floodable reservoir volumes, WiD (generated within the program for equal intervals and input from data for unequal intervals);

3) values of $\frac{t \Delta P}{\phi \mu_w A}$ which are arbitrarily selected (input from data) for the calculation of the mass fractions;

4) the effective permeabilities of the various layers to water and the respective thicknesses of these layers (input as data in subroutine PLAY);

5) the water cut approximation is stored in subroutine H20CUT;

6) the cumulative water injection per five-spot pore volume at water breakthrough (WBTH), is obtained from least squares fits of sweep efficiency as a function of water-oil mobility ratio, and sweep efficiency is obtained as a function of cumulative water injection per five-spot pore volume; a family of both of these curves is presented in the original manuscript.
IV. SAMPLE CALCULATIONAL PROCEDURE

The following parameters are representative of a reservoir in the Illinois Basin and are input into the program in subroutine VALU:

\[
\begin{align*}
S_0 &= 0.558 \\
S_{or} &= 0.144 \\
S_g &= 0.242 \\
S_{gr} &= 0.000 \\
S_{wc} &= 0.200 \\
k_{rw} &= 0.10 \\
k_{ro} &= 0.133 \\
k_{rg} &= 0.148 \\
\mu_w &= 0.87 \text{ cp.} \\
\mu_o &= 3.5 \text{ cp.} \\
\mu_g &= 0.013 \text{ cp.} \\
L &= 933 \text{ ft.} \\
r_w &= 2 \text{ ft. (assumed effective radius)} \\
\phi &= 0.176 \\
M_{w,o} &= 3.0 \\
M_{o,g} &= 0.0033
\end{align*}
\]

From the given data, the displacement factor, \( F \), is then determined in statement 14 of the program. For a series of arbitrarily selected dimensionless cumulative injection values, \( W_{iD} \), corresponding injectivities \( I_D \) are calculated for Periods 1 and 2 employing the equations of the original technique. It is noteworthy to point out that subroutine
TRAP is employed for the determination of areas under the injectivity curve and makes use of the Trapezoidal rule for these calculations. Subroutine PLAY is called only once and by means of this subroutine the permeabilities of the various layers are obtained. For arbitrarily selected values of the cumulative injectivity, the quasi-radius, \( r_4 \), and subsequently, the dimensionless injectivity are calculated for Period 3A, after the terminal value of the cumulative water injection has been determined from a plot of the cumulative injection as a function of water-to-oil mobility and displacement factor. The fourth-order polynomial approximation for the dimensionless injectivity is then employed to determine suitable values for Period 3B. By relating the reciprocal of the dimensionless injectivity versus the cumulative injection and integrating under the curve by means of subroutine TRAP it is possible to relate injectivity to real time. The fractions produced in each layer are then determined in terms of injectivity through use of a search technique which may then be summed in order to determine a total injectivity based on real time, from which the fractions present are calculated.

At a comparative real time of 0.060 md.\(^{-1}\), the oil and water fractions were 0.175 and 0.744, respectively, for this technique. The fractions obtained in the original technique at the same comparative real time were 0.170 for oil, and 0.749 for water.
V. RESULTS

The applications yielded low average deviations, as indicated in Figures IV and V. The oil fraction in the efflux had an average deviation of 9.37% from the values recorded by Prats; however, on omission of the point having the greatest deviation, 6.00% deviation resulted. This point, which occurred after water breakthrough, differed from that of the original technique by at most, 6.50% of the comparative real time differential. The gas fraction deviated by 4.89% with a contrary point occurring at the same time as that of the oil fraction. Eliminating this point, the gas fraction had an absolute average deviation of 1.67%.

The derived dimensionless injectivity equation which applies from oil breakthrough until water bank interference, or Period 3A, was found to have an average deviation of 0.731% on injectivity from the values employed by Prats, which was quite acceptable.

The fourth-order dimensionless injectivity approximation after water breakthrough, Period 3B, had an average deviation of 0.233% and a maximum deviation of 0.573%, which was quite low and most acceptable.
FIGURE IV. PERCENT DEVIATION AS A FUNCTION OF OIL FRACTION
FIGURE V. PER CENT DEVIATION AS A FUNCTION OF GAS FRACTION
**PERIOD 1**

**WIN (MAXIMUM) = 2.289736**

<table>
<thead>
<tr>
<th>WIN</th>
<th>$R_{1**2}$</th>
<th>$R_{2**2}$</th>
<th>ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>61.2266</td>
</tr>
<tr>
<td>0.010</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.3007</td>
</tr>
<tr>
<td>0.020</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.2143</td>
</tr>
<tr>
<td>0.030</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.1690</td>
</tr>
<tr>
<td>0.040</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.1388</td>
</tr>
<tr>
<td>0.050</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.1164</td>
</tr>
<tr>
<td>0.060</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.0888</td>
</tr>
<tr>
<td>0.070</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.0721</td>
</tr>
<tr>
<td>0.080</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.0615</td>
</tr>
<tr>
<td>0.090</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.0527</td>
</tr>
<tr>
<td>0.100</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.0440</td>
</tr>
<tr>
<td>0.110</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.0366</td>
</tr>
<tr>
<td>0.120</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.0289</td>
</tr>
<tr>
<td>0.130</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.0237</td>
</tr>
<tr>
<td>0.140</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.0180</td>
</tr>
<tr>
<td>0.150</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.0128</td>
</tr>
<tr>
<td>0.160</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.0079</td>
</tr>
<tr>
<td>0.170</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>1.0033</td>
</tr>
<tr>
<td>0.180</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>0.9991</td>
</tr>
<tr>
<td>0.190</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>0.9951</td>
</tr>
<tr>
<td>0.200</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>0.9913</td>
</tr>
<tr>
<td>0.210</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>0.9877</td>
</tr>
<tr>
<td>0.220</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>0.9843</td>
</tr>
<tr>
<td>0.230</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>0.9810</td>
</tr>
<tr>
<td>0.240</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>0.9779</td>
</tr>
<tr>
<td>0.250</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>0.9750</td>
</tr>
<tr>
<td>0.260</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>0.9722</td>
</tr>
<tr>
<td>0.270</td>
<td>0.4076F 04</td>
<td>0.4076F 04</td>
<td>0.9695</td>
</tr>
</tbody>
</table>

**PERIOD 2**

**WIN (MAXIMUM) = 0.368902**

<table>
<thead>
<tr>
<th>WIN</th>
<th>$R_{1**2}$</th>
<th>$R_{2**2}$</th>
<th>ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.200</td>
<td>0.8036F 05</td>
<td>0.5927E 05</td>
<td>0.9210</td>
</tr>
<tr>
<td>0.210</td>
<td>0.8036F 05</td>
<td>0.5927E 05</td>
<td>0.6988</td>
</tr>
<tr>
<td>0.220</td>
<td>0.8036F 05</td>
<td>0.5927E 05</td>
<td>0.8736</td>
</tr>
<tr>
<td>0.230</td>
<td>0.8036F 05</td>
<td>0.5927E 05</td>
<td>0.8447</td>
</tr>
<tr>
<td>0.240</td>
<td>0.8036F 05</td>
<td>0.5927E 05</td>
<td>0.8108</td>
</tr>
<tr>
<td>0.250</td>
<td>0.8036F 05</td>
<td>0.5927E 05</td>
<td>0.7596</td>
</tr>
<tr>
<td>0.260</td>
<td>0.8036F 05</td>
<td>0.5927E 05</td>
<td>0.7165</td>
</tr>
<tr>
<td>0.270</td>
<td>0.8036F 05</td>
<td>0.5927E 05</td>
<td>0.6368</td>
</tr>
<tr>
<td>WIN</td>
<td>R4*2</td>
<td>ID</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>-------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>0.3000</td>
<td>0.1261E 06</td>
<td>0.3032</td>
<td></td>
</tr>
<tr>
<td>0.4000</td>
<td>0.1182E 06</td>
<td>0.3042</td>
<td></td>
</tr>
<tr>
<td>0.4200</td>
<td>0.1102E 06</td>
<td>0.3052</td>
<td></td>
</tr>
<tr>
<td>0.4400</td>
<td>0.1023E 06</td>
<td>0.3063</td>
<td></td>
</tr>
<tr>
<td>0.4600</td>
<td>0.9435E 05</td>
<td>0.3075</td>
<td></td>
</tr>
<tr>
<td>0.4800</td>
<td>0.8660E 05</td>
<td>0.3089</td>
<td></td>
</tr>
<tr>
<td>0.5000</td>
<td>0.7966E 05</td>
<td>0.3103</td>
<td></td>
</tr>
<tr>
<td>0.5200</td>
<td>0.7051E 05</td>
<td>0.3120</td>
<td></td>
</tr>
<tr>
<td>0.5400</td>
<td>0.6257E 05</td>
<td>0.3138</td>
<td></td>
</tr>
<tr>
<td>0.5600</td>
<td>0.5462E 05</td>
<td>0.3160</td>
<td></td>
</tr>
<tr>
<td>0.5800</td>
<td>0.4668E 05</td>
<td>0.3185</td>
<td></td>
</tr>
<tr>
<td>0.6000</td>
<td>0.3873E 05</td>
<td>0.3215</td>
<td></td>
</tr>
<tr>
<td>0.6200</td>
<td>0.3079E 05</td>
<td>0.3254</td>
<td></td>
</tr>
<tr>
<td>0.6400</td>
<td>0.2284E 05</td>
<td>0.3305</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WIN</th>
<th>H2O CUT</th>
<th>ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6500</td>
<td>0.00000000</td>
<td>0.3360</td>
</tr>
<tr>
<td>0.7000</td>
<td>0.38924898</td>
<td>0.3837</td>
</tr>
<tr>
<td>0.8000</td>
<td>0.56943328</td>
<td>0.4337</td>
</tr>
<tr>
<td>0.9000</td>
<td>0.65704573</td>
<td>0.4724</td>
</tr>
<tr>
<td>1.0000</td>
<td>0.74600000</td>
<td>0.5055</td>
</tr>
<tr>
<td>1.5000</td>
<td>0.89899999</td>
<td>0.5652</td>
</tr>
<tr>
<td>2.0000</td>
<td>0.97800000</td>
<td>0.5968</td>
</tr>
</tbody>
</table>
### VALUES OF ID(T)*KJ*HJ/&KJ*HJ FOR LAYER

<table>
<thead>
<tr>
<th>MD** (-1)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>IDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0000</td>
<td>16.0126</td>
<td>29.4412</td>
<td>12.7551</td>
<td>4.0374</td>
<td>61.2464</td>
</tr>
<tr>
<td>0.0005</td>
<td>0.2757</td>
<td>0.5333</td>
<td>0.2585</td>
<td>0.0177</td>
<td>2.0851</td>
</tr>
<tr>
<td>0.0010</td>
<td>0.2622</td>
<td>0.5062</td>
<td>0.2451</td>
<td>0.0043</td>
<td>1.0977</td>
</tr>
<tr>
<td>0.0020</td>
<td>0.2061</td>
<td>0.4809</td>
<td>0.2326</td>
<td>0.0040</td>
<td>0.9996</td>
</tr>
<tr>
<td>0.0024</td>
<td>0.1103</td>
<td>0.4745</td>
<td>0.2296</td>
<td>0.0792</td>
<td>0.8935</td>
</tr>
<tr>
<td>0.0060</td>
<td>0.0825</td>
<td>0.3942</td>
<td>0.2145</td>
<td>0.0739</td>
<td>0.7551</td>
</tr>
<tr>
<td>0.0076</td>
<td>0.0865</td>
<td>0.1781</td>
<td>0.2109</td>
<td>0.0726</td>
<td>0.5480</td>
</tr>
<tr>
<td>0.0080</td>
<td>0.0807</td>
<td>0.1409</td>
<td>0.2103</td>
<td>0.0724</td>
<td>0.5132</td>
</tr>
<tr>
<td>0.0100</td>
<td>0.1115</td>
<td>0.1416</td>
<td>0.2068</td>
<td>0.0711</td>
<td>0.5144</td>
</tr>
<tr>
<td>0.0150</td>
<td>0.1393</td>
<td>0.1439</td>
<td>0.1886</td>
<td>0.0690</td>
<td>0.5310</td>
</tr>
<tr>
<td>0.0200</td>
<td>0.1502</td>
<td>0.1478</td>
<td>0.1116</td>
<td>0.0676</td>
<td>0.4771</td>
</tr>
<tr>
<td>0.0213</td>
<td>0.1522</td>
<td>0.1493</td>
<td>0.0767</td>
<td>0.0673</td>
<td>0.4455</td>
</tr>
<tr>
<td>0.0245</td>
<td>0.1560</td>
<td>0.1590</td>
<td>0.0633</td>
<td>0.0666</td>
<td>0.4439</td>
</tr>
<tr>
<td>0.0272</td>
<td>0.1560</td>
<td>0.1785</td>
<td>0.0635</td>
<td>0.0661</td>
<td>0.4641</td>
</tr>
<tr>
<td>0.0280</td>
<td>0.1560</td>
<td>0.2351</td>
<td>0.0644</td>
<td>0.0643</td>
<td>0.5199</td>
</tr>
<tr>
<td>0.0500</td>
<td>0.1560</td>
<td>0.2504</td>
<td>0.0654</td>
<td>0.0570</td>
<td>0.5291</td>
</tr>
<tr>
<td>0.0600</td>
<td>0.1560</td>
<td>0.2646</td>
<td>0.0671</td>
<td>0.0424</td>
<td>0.5301</td>
</tr>
</tbody>
</table>

### FG

<table>
<thead>
<tr>
<th>MD** (-1)</th>
<th>FG</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0000</td>
<td>1.00000</td>
</tr>
<tr>
<td>0.0005</td>
<td>1.00000</td>
</tr>
<tr>
<td>0.0010</td>
<td>1.00000</td>
</tr>
<tr>
<td>0.0020</td>
<td>1.00000</td>
</tr>
<tr>
<td>0.0040</td>
<td>0.87656</td>
</tr>
<tr>
<td>0.0075</td>
<td>0.80073</td>
</tr>
<tr>
<td>0.0100</td>
<td>0.51722</td>
</tr>
<tr>
<td>0.0200</td>
<td>0.56877</td>
</tr>
<tr>
<td>0.0400</td>
<td>0.54895</td>
</tr>
<tr>
<td>0.0800</td>
<td>0.52333</td>
</tr>
<tr>
<td>0.1500</td>
<td>0.47715</td>
</tr>
<tr>
<td>0.2000</td>
<td>0.14167</td>
</tr>
<tr>
<td>0.2130</td>
<td>0.15104</td>
</tr>
<tr>
<td>0.2450</td>
<td>0.15066</td>
</tr>
<tr>
<td>0.2700</td>
<td>0.14252</td>
</tr>
<tr>
<td>0.4000</td>
<td>0.12375</td>
</tr>
<tr>
<td>0.5000</td>
<td>0.10779</td>
</tr>
<tr>
<td>0.6000</td>
<td>0.08004</td>
</tr>
</tbody>
</table>

### FN

<table>
<thead>
<tr>
<th>MD** (-1)</th>
<th>FN</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0000</td>
<td>0.00000</td>
</tr>
<tr>
<td>0.0005</td>
<td>0.00000</td>
</tr>
<tr>
<td>0.0010</td>
<td>0.00000</td>
</tr>
<tr>
<td>0.0020</td>
<td>0.00000</td>
</tr>
<tr>
<td>0.0040</td>
<td>0.12344</td>
</tr>
<tr>
<td>0.0075</td>
<td>0.10927</td>
</tr>
<tr>
<td>0.0100</td>
<td>0.43839</td>
</tr>
<tr>
<td>0.0200</td>
<td>0.39446</td>
</tr>
<tr>
<td>0.0400</td>
<td>0.39360</td>
</tr>
<tr>
<td>0.0800</td>
<td>0.36566</td>
</tr>
<tr>
<td>0.1500</td>
<td>0.30493</td>
</tr>
<tr>
<td>0.2000</td>
<td>0.57344</td>
</tr>
<tr>
<td>0.2130</td>
<td>0.53613</td>
</tr>
<tr>
<td>0.2450</td>
<td>0.38903</td>
</tr>
<tr>
<td>0.2700</td>
<td>0.37073</td>
</tr>
<tr>
<td>0.4000</td>
<td>0.23664</td>
</tr>
<tr>
<td>0.5000</td>
<td>0.18301</td>
</tr>
<tr>
<td>0.6000</td>
<td>0.17549</td>
</tr>
</tbody>
</table>

### FW

<table>
<thead>
<tr>
<th>MD** (-1)</th>
<th>FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0000</td>
<td>-0.00000</td>
</tr>
<tr>
<td>0.0005</td>
<td>-0.00000</td>
</tr>
<tr>
<td>0.0010</td>
<td>-0.00000</td>
</tr>
<tr>
<td>0.0020</td>
<td>-0.00000</td>
</tr>
<tr>
<td>0.0040</td>
<td>0.04439</td>
</tr>
<tr>
<td>0.0075</td>
<td>0.54477</td>
</tr>
<tr>
<td>0.0100</td>
<td>0.05745</td>
</tr>
<tr>
<td>0.0200</td>
<td>0.11102</td>
</tr>
<tr>
<td>0.0400</td>
<td>0.21797</td>
</tr>
<tr>
<td>0.0800</td>
<td>0.28490</td>
</tr>
<tr>
<td>0.1500</td>
<td>0.31283</td>
</tr>
<tr>
<td>0.2000</td>
<td>0.46091</td>
</tr>
<tr>
<td>0.4000</td>
<td>0.48675</td>
</tr>
<tr>
<td>0.5000</td>
<td>0.63961</td>
</tr>
<tr>
<td>0.6000</td>
<td>0.70921</td>
</tr>
<tr>
<td>0.74447</td>
<td></td>
</tr>
</tbody>
</table>
VI. CONCLUSIONS

The technique of Prats for calculating the fractions of oil, water, and gas by use of an electrolytic model has been converted to a digitalized solution without the necessity of electrolytic model interim data determinations.

This technique is advantageous in that it does not require a knowledge of either pressure drops or time elapsed at any point in the calculation to predict performance. If desired, the time elapsed may be determined at any given production fractions.

The adapted version requires a knowledge of the water cut as a function of the total amount of water injected in lieu of the electrolytic model, which allows all results to be obtained through a rigorous mathematical procedure only, which is readily available.

In employing the adapted version, it is still necessary to note that, as with the original technique, the calculations become tedious unless a small number of permeability layers may be discerned.

In summary, we conclude that a technique adaptable to digital solution has been offered which modifies the Prats' technique such that production histories for a five-spot water flood can be accurately and rapidly projected.
BIBLIOGRAPHY


APPENDIX
<table>
<thead>
<tr>
<th>Theoretical Discussion</th>
<th>Computer Program</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_S$</td>
<td>FG</td>
<td>sweep efficiency</td>
</tr>
<tr>
<td>$f_g$</td>
<td>FO</td>
<td>fraction of gas in efflux</td>
</tr>
<tr>
<td>$f_o$</td>
<td>FW</td>
<td>fraction of oil in efflux</td>
</tr>
<tr>
<td>$f_w$</td>
<td>F</td>
<td>fraction of water in efflux</td>
</tr>
<tr>
<td>$I_D$</td>
<td>ID( )</td>
<td>dimensionless injectivity</td>
</tr>
<tr>
<td>$I_D(t)$</td>
<td>SUMID( )</td>
<td>dimensionless injectivity as a function of time</td>
</tr>
<tr>
<td>$h_j$</td>
<td>RHJ( )</td>
<td>thickness of the $j$-th layer; feet</td>
</tr>
<tr>
<td>$k_{w_j}$</td>
<td>WJK( )</td>
<td>effective permeability of the $j$-th layer to water; md.</td>
</tr>
<tr>
<td>$M_{o,g}$</td>
<td>MOG</td>
<td>mobility ratio, oil to gas</td>
</tr>
<tr>
<td>$M_{w,o}$</td>
<td>MWO</td>
<td>mobility ratio, water to oil</td>
</tr>
<tr>
<td>$(r_1)^2$</td>
<td>SQR1( )</td>
<td>square of the outer radius of the water bank during Periods 1 and 2; feet</td>
</tr>
<tr>
<td>$(r_2)^2$</td>
<td>SQR2( )</td>
<td>square of the outer radius of the oil bank during Period 1; feet</td>
</tr>
<tr>
<td>$(r_3)^2$</td>
<td>SQR3( )</td>
<td>square of the outer radius of the gas region around the production well during Period 2; feet</td>
</tr>
<tr>
<td>$(r_4)^2$</td>
<td>SQR4( )</td>
<td>square of the quasi-radius of water flowing under interference during Period 3A; feet</td>
</tr>
</tbody>
</table>

*Computer alphameric not listed in this table which are primary variables are the same as listed in SPE Standard "Letter Symbols for Petroleum Reservoir Engineering, Natural Gas Engineering and Well Logging Quantities", 1965.
<table>
<thead>
<tr>
<th>Theoretical Discussion</th>
<th>Computer Program</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>((r_w)^2)</td>
<td>SQRW</td>
<td>square of the radius of the injection well; feet</td>
</tr>
<tr>
<td>L</td>
<td>L</td>
<td>length of the side of five-spot pattern; feet</td>
</tr>
</tbody>
</table>

Parentheses following a computer program variable indicate a dimensioned quantity.
DIMENSION WID(100), SOR1(50), SOR2(50), ID(100), ID1(100), T7(100),
IDM1(5), RSM1(5), SOR3(50), DML1(100), DML2(100), DML3(100), DML4(100),
ID0(100), WC0(100), TEFC (20), RLL (20), R2L (20), R3L (20), R4L (20),
R5L (20), SW1 (20), SW2 (20), SQR4 (55)

INTEGER PERIOD

REAL ID, KRW, KRG, MW, MO, MGL, MWD, MGD, IDP

COMMON KRW, KRG, MW, MO, MGL, MD, SOR, SG, SGR, SWC, RW, PHI, MWD, MGD

C

CALL VALU
N1 = ?

WRITE (3, 3)

3 FORMAT ('I', 50X, 'PRATS COMPUTATION')

WRITE (3, 1) PERIOD

8 FORMAT ('///', 40X, 'PERIOD', I2)

SOR1 = P**2

A = 1 + ((SG - SOR1) / (SG - SGR))

WRITE (3, 2) A

Y1 = 1.0

2 FORMAT (RAX, Y = 1.0, F 10.6)

WID1 = C

WRITE (3, 4) WIDMAX

WRITE (3, 22) WIDMAX

22 FORMAT (RAX, WID (MAXIMUM) = *, F 10.6)

NC = 1, NC

IF (IA > NC) GO TO 4

WRITE (IA + 1) = WID(IA) + 0.01

SOR1(IA) = WID(IA) + 0.01

SOR2(IA) = WID(IA) + 0.01

SORT(IA) = WID(IA) + 0.01

SQR(IA) = WID(IA) + 0.01

I = 1, R = 1, NC

CONTINUE

WRITE (3, 9)

6 FORMAT ('///', T37, W1D, T36, 'R1**2', T78, 'R2**2', T1C7, 'ID')

WRITE (3, 6) WID(1), SOR1(1), SOR2(1), ID(1), IA = 1, NC

WRITE (3, 10) TIC, IA = 1, NC

WRITE (3, 11) ID, NC, T7, N1, XH

5 FORMAT (30X, F10.6)

6 FORMAT (30X)
ID(IA) = (4. * PI) / (ALOG(SQR1(IA)/SQRW) + MWO * MOC * ALOG(SQR3(IA)/SQRW) + 1.5 * PI2 * ALOG(A/SORW) - 3.956 - ALOG(SQR3(IA)/SQRW) - ALOG(SQR1(IA)/2 * SORW))

10 CONTINUE

WRITE (3, 10)

10 FORMAT (/*/T37, 'WIN ', T56, 'R1**2 ', T78, 'R3**2 ', T102, 'ID*')

WRITE (3, 6) (WIN(I), SOR1(IA), SOR3(IA), ID(I), ID = NCP, ND)

CALL TRAP (NID, ND, T7, NCP, XH)

21 FORMAT (7(5X, F10.4))

CALL PLAY (RMD1, RSUM)

C

PERIOD = 3
WRITE (3, 9) PERIOD
C
THIS IS PERIOD 3A:
DO 26 I = 38, 51
XH = 0, 0
WIN(IN) = WIN(IN-1) + XH
SQR4(IN) = (1**2) * (SO - WIN(IN) * (1 - SWC)) / (PI * SQ)
ID(IN) = (7. * PI) / (2 * (ALOG(L/RW) - 0.064) + (MWO - 1) * ALOG(SORT(SQR(SQR4(IN)))

C

NID(IN) = 1 / ID(IN)

26 CONTINUE

26 CALL TRAP (NID, 51, T7, 38, XH)

27 FORMAT (/*/T37, 'WIN ', T56, 'R4**2 ', T102, 'ID*')

WRITE (3, 27) (WIN(IN), SOR4(IN), ID(IN), IN = 38, 51)

C

27 FORMAT (7(5X, F10.4))

DO 71 I = 38, 51
READ (1, 23) (WIN(IN), IM = 52, 58)

23 CONTINUE

C

WRTH = 0, 65

C

DO 74 J = 52, 59
CALL W2OUT (WIN(I), WC(I), WRTH)

74 ID(I) = 0.336 - 0.064 * WC(I) + 0.700 * WC(I)**2 - 0.465 * WC(I)**3

C

75 WIN(IN) = WIN(IN-1) - XH

76 CALL TRAP (NID, T7, I, XH)

24 CONTINUE

24 WRITE (3, 25)

25 FORMAT (/*/T37, 'WIN ', T54, 'H20 CUT* ', T102, 'ID*')

WRITE (3, 105) (WIN(I), WC(I), ID(I), I = 52, 58)

105 FORMAT (3(5X, F10.4))

DO 22 IF = 1, 58

22 CONTINUE

22 WRITE (3, 48)


1T6A, 'LAYER 3* ', T3R, 'LAYER 4* ', T101, 'ID*')

WRITE (3, 21) (WIN(IC), T7(IC), DML1(IC), DML2(IC), DML3(IC), DML4(IC),

1DOR1(1), IF = 1, 58)
```
148 IF (IG, EO, 1) GCOUNT = GCL (I) + GCOUNT
149 IF (IG, EO, 1) GCOUNT = GCOUNT + P2L (I)
150 IF (IG, EO, 1) OR IG, EO, 1) GO TO 201
151 DWIN = WID (IA-1) + (WID (IA) - WID (IA-1)) * ((TETC (I) - DML2 (IA-1)) / DML2 (IA)
1 - DML2 (IA-1))
152 CALL H2DOUC (DWIN, FW, WTH)
153 GCOUNT = GCOUNT + P2L (I) * (1 - FW)
154 201 IF (TETC (I), L, DML3 (IA-1), OR TETC (I), GE, DML3 (IA)) GO TO 202
155 CALL SPAC (IA, ND, NWTH, IG, EO)
156 IF (IG, EO, 1) GCOUNT = P3L (I) + GCOUNT
157 IF (IG, EO, 1) GCOUNT = GCOUNT + R3L (I)
158 IF (IG, EO, 1) OR IG, EO, 1) GO TO 202
159 DWIN = WID (IA-1) + (WID (IA) - WID (IA-1)) * ((TETC (I) - DML3 (IA-1)) / DML3 (IA)
1 - DML3 (IA-1))
160 CALL H2DOUC (DWIN, FW, WTH)
161 GCOUNT = GCOUNT + P3L (I) * (1 - FW)
162 202 IF (TETC (I), L, DML4 (IA-1), OR TETC (I), GF, DML4 (IA)) GO TO 151
163 CALL SPAC (IA, ND, NWTH, IG, EO)
164 IF (IG, EO, 1) GCOUNT = P4L (I) + GCOUNT
165 IF (IG, EO, 1) GCOUNT = GCOUNT + R4L (I)
166 IF (IG, EO, 1) OR IG, EO, 1) GO TO 151
167 DWIN = WID (IA-1) + (WID (IA) - WID (IA-1)) * ((TETC (I) - DML4 (IA-1)) / DML4 (IA)
1 - DML4 (IA-1))
168 CALL H2DOUC (DWIN, FW, WTH)
169 GCOUNT = GCOUNT + R4L (I) * (1 - FW)
170 CONTINUE
171 TETAC = P11 (I) + P2L (I) + P3L (I) + P4L (I)
172 EG = GCOUNT / TETAC
173 FD = GCOUNT / TETAC
174 FW = 1 - (EC + FD)
175 WRITE (3, 42) TETC (I), EG, EO, FW
176 CONTINUE
177 STOP
178 END
179 SUBROUTINE VALU
180 COMMON KRW, KRG, KPG, MW, MO, MG, L, SO, SGR, SG, SGR, SWC, RW, PHI, MWO, MOG
181 REAL ID, KRW, KRG, KPG, MW, MO, MG, L, MWO, MOG
182 121 PI = 3.1416
183 CO = 0.588
184 SQ = 3.14
185 CG = 2.12
186 SG = 0.12
187 CWC = 0.12
188 KOV = 0 1
189 KOG = 0.132
190 KG = 0.148
191 MW = 0.07
192 MD = 0.7
193 MC = 0.12
194 L = 0.3
195 MD = 0.12
196 DT = 0.174
197 SOC = 0.33
198 CTRUEN
```
SUBROUTINE TRAP (NID,NC,T7,J,XH)
DIMENSION T7(100),Q1D(100)
T7(1)=0
DO 100 IA=J,NC
Q=QH/2.*QID(IA-1)+QID(IA)
100 T7(IA)=T7(IA-1)+Q
RETURN
END

SUBROUTINE PLAY (RND1,RSUM)
DIMENSION RMD1(5),WJK(5),RHJ(5),RSUM(5)
LAYER=4
READ (1,101) (WJK(IA),IA=1,LAYER)
READ (1,101) (RHJ(IA),IA=1,LAYER)
101 FORMAT (7F10.4)
ADD=0
DO 102 IB=1,LAYER
RHJ(IB)=RHJ(IB)*WJK(IB)
ADD=ADD+RHJ(IB)
102 CONTINUE
ADD=ADD/LAYER
RSUM(IB)=RHJ(IB)/ADD
RETURN
END

SUBROUTINE H2OCUT (A,B,C)
A=.
IF (A.EQ.0) GO TO 99
B=-1.69+5.46*A-3.46*A**2+0.736*A**3
99 RETURN
END

SUBROUTINE FRAC (T,N,M,IG,IO)
IO=0
IG=0
IF (T.LE.N) IG=1
IF (IG.LE.1) GO TO 99
IF (T.LE.M) IO=1
99 RETURN
END

DATA
**SUBROUTINE TRAP**

**FLOWCHARTER II**

**SUBROUTINE TRAP** (OIO,NC,TZ,J,XH)

1. **TT(1) = 0.**
2. **DO 100 IA=J,NC**
3. **IA = J - 1**
4. **IA = IA + 1**
5. **O = (XH/2) * (01 * (IA-1) + 01 * (IA))**
6. **100**
7. **TT(IA) = TZ(IA-1)**
8. **S100**
9. **RETURN**
SUBROUTINE PLAY (RMO1, RSUM)

LAYER = 4

READ (1, 101)
  (RMO1, IA = LAYER)

READ (1, 101)
  (RMO1, IA = LAYER)

AEE = 0.

DO 102 IN = 1, LAYER

IC = IC + 1

DO 103 IC = 1, LAYER

RHO (IC) = RHO (IC) + RHO (IB)

XY (IC) = XY (IC) + XY (IB)

IF (IC .GE. LAYER) THEN
  RETURN
END

RETURN
SUBROUTINE H2OCUT (A, B, C)

B = 0.

*NO*

(A .EQ. C) \( \rightarrow A3 \)

*YES*

\( \rightarrow A4 \)

S99

** B = -1.99 + 5.46
** A = -3.46 * A ** 2 + 0
** \( A3 \rightarrow 0.736 * A ** 3 \)

S99

** RETURN
SUBROUTINE FRAC (I, N, M, IG, IO)

ID = 0

IG = 0

IF (I .LE. M) THEN
   YES
   IG = 1
   A6)
   RETURN

IF (IG .EQ. 1) THEN
   YES
   A6)
   S99

IF (I .LE. M) THEN
   YES
   A6)
   S99

IO = 1

RETURN
VITA

LEONARD FREDERICK KOEDERITZ

Born - August 21, 1946, at St. Louis, Missouri
Married
Graduate of University of Missouri-Rolla
Bachelor of Science, Chemical Engineering

Professional Record:
Linde Division of Union Carbide, Summers of 1965, 1966, 1967