Prediction of Oil Production of Individual Operator in a Multiple Leases Reservoir

M. N. Mohamad Ibrahim

School of Chemical Sciences, Universiti Sains Malaysia,
11800 Pulau Pinang, Malaysia, mnm@usm.my

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Abstract. This paper presents a commonly existing problem in a multiple leases reservoir and tries to solve it using a boundary element method approach. The developed Boundary Element Method (BEM) formulation in calculating the productivity of well or clusters of wells located arbitrarily in an irregularly shaped reservoir was employed in this study to determine the total oil production for each operator that share a single reservoir. In this example application, two operators of equal area shared one circular oil reservoir. Different operator or section of the reservoir is assigned with different drilling pattern. The section that is developed with a four-spot drilling pattern produces 19% more oil compared to the section developed with a five-spot pattern. The case of adding injector wells into the system is also presented. Results showed that the difference between four-spot and five-spot patterns in term of oil production is less pronounce when injector wells were introduced to the system.

Introduction

Recently several major oil companies merged with each other in perusing their business. Besides to strengthen their capital and human resource, this step inevitable will help to minimize unnecessary court case that may occur among them especially when dealing with a multiple leases reservoir.

The multiple leases reservoir refers to a single oil reservoir that is having more than one operator working on it. This phenomenon can easily be seen in countries that have many small operators who have limited capital to bid for the whole lease. They will end up sharing the reservoir based on their working interest or the amount of capital that they are willing to invest.

While the boundary and the area of each operator can be specified on a map, one cannot be sure what is happening more than 1,000 feet underground follows exactly as what was planned earlier. Different drilling pattern for example will give different total oil production due to their differences in aerial sweep efficiency. This study presents a commonly existing problem among different operators in a multiple leases reservoir and tries to solve it using a boundary element method approach.

BEM Formulation

Differential equation describing the pressure distribution at all points in an oil reservoir is [1,2,3,4]:

$$\frac{\partial^2 p}{\partial X^2}+\frac{\partial^2 p}{\partial Y^2}+\frac{\mu}{k}\sum_{m=1}^{NSS} q_m\ \delta(X-X_m, Y-Y_m)=0 \qquad (1)$$

where p is pressure, μ is the dynamic viscosity of the fluid, k is the permeability, q_m is the flow rate of the m^{th} well per unit area (positive for injectors and negative for producers), δ is the Dirac delta function, X, Y are coordinates axes, and X_m , Y_m are coordinates of the m^{th} source and/or sink where m varies from 1 to NSS.

Eq (1) can be transformed into an integral equation by multiplying it with the free-space Green's function and integrating it twice by parts. The free-space Green's function, also called the fundamental solution [5] is given as:

$$G=\frac{1}{2\pi}\ \ln\left(\frac{1}{r}\right) \qquad (2)$$

where r is the distance between a field point (X, Y) and a point of application of a unit charge (X_C, Y_C). After standard manipulation [1], Eq (1) then becomes:

$$\alpha p\ (X_i, Y_i) = \frac{1}{2\pi} \Sigma_{j=1}^{N} \frac{\partial p}{\partial n_j} \int_{sj} \ln\left(\frac{1}{r_{i,j}}\right) ds - \frac{1}{2\pi} \Sigma_{j=1}^{N} p_j \int_{sj} \frac{\partial}{\partial n}\left[\ln\left(\frac{1}{r_{i,j}}\right)\right] ds + \frac{1}{2\pi} \frac{\mu}{k} \Sigma_{m=1}^{NSS} q_m \ln\left(\frac{1}{r_{i,m}}\right) \qquad (3)$$

where the boundary of the reservoir is divided into N constant elements with constant properties. α is the included angle at the i^{th} pivot point. It is assigned a value of ½ when the pivot point is on a smooth boundary (*i.e.* not on a corner), and a value of 1 when the pivot point is inside the problem domain.

The integral equations are written for boundary points as well as for the locations of the point sources and/or sinks (producer and/or injector wells). A solution of the resulting equation gives the value of flow rate, q, for each of the well directly as well as the unknown boundary values of pressure p and pressure gradient dp/dn. The formulation was coded into a computer program namely FORTRAN which allows a rapid analysis process.

Example Application

Consider a hypothetical homogeneous circular oil reservoir having the following properties:

$Area$ = 314.2 x 10^6 feet^2 = 7,212 acre (reservoir area),
r_w = 0.25 feet (well-bore radius),
k = 100 md (absolute permeability), ϕ = 0.15 (reservoir porosity),
h = 35 feet (reservoir thickness),
ρ = 62.4 lb/ft^3 (reservoir fluid density),
μ = 1.0 cp (fluid viscosity), p_w = 100 psi (well-bore pressure),
p_e = 2,000 psi (external reservoir pressure) and
$Scale$ = 1: 5,000

This newly discovered reservoir is going to be developed by two operators (A and B) at equal area. Different operator or section of the reservoir is assigned with different drilling pattern *i.e.* four-spot (B) and five-spot (A) drilling pattern respectively. Four-spot drilling pattern refers to a single pattern that is formed by four wells. The shape of the pattern is a triangle with one well located in the middle while the rest of the wells located each at the tip of the triangle. This pattern can be expanded side by side depending on the requirement. The same also true for the five-spot pattern where five wells are needed to form a single pattern of square shaped [6]. These patterns are shown in Fig. 1 where the solid lines connecting some of the wells represent the complete pattern whereas the dotted lines represent the incomplete pattern.

With the area of each pattern remain the same (6.25 x 10^6 feet^2 = 143.5 acre) regardless of the pattern shape; each section of the reservoir is developed by 22 producer wells (the well that produces oil). The case of adding injector wells (the well that is used to inject or pump water into the reservoir in order to maintain the reservoir pressure) into the system is also presented. Four producer wells in each section of the reservoir are converted to injector wells. The injection rate was set to be 1,000 barrel of water per day. The location of these wells is shown in Fig. 2.

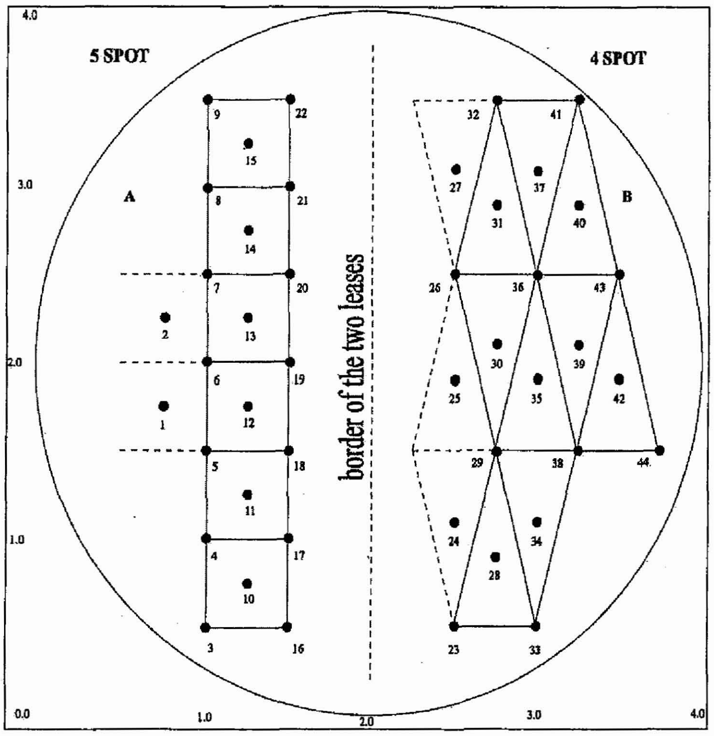

Fig. 1. Two operators of equal area shared one circular oil reservoir and developed the reservoir with two different drilling patterns

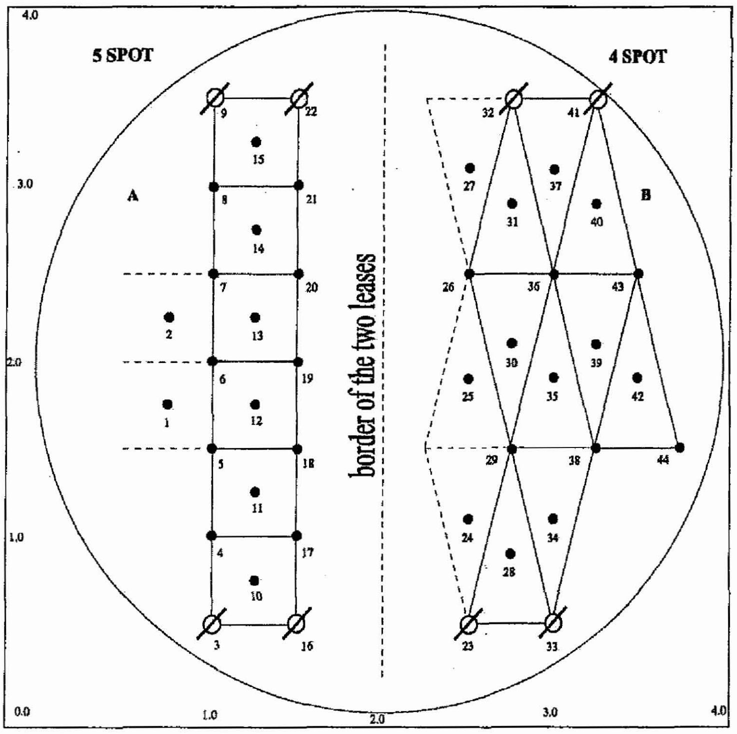

Fig. 2. Eight injector wells were introduced into the system

Results and Discussion

Complete simulation results obtained from the above studies in barrel per day (bbl/d) were compared and summarized in Table 1.

Item		*Operator A*	*Operator B*
Well Type	Drilling Pattern	5-spot	4-spot
All Producers	Total Oil Production, Q_n (bbl/d)	46,305	55,020
	Average Production per Well, Q_{avg} (bbl/d)	2,105	2,501
4 injector wells in each section	Total Oil Production, Q_n (bbl/d)	204,949	211,578
	Average Production per Well, Q_{avg} (bbl/d)	11,386	11,754

Table 1. Production data for two different operators

Obviously from Table 1, four-spot pattern is more superior compared to five-sport pattern in terms of Q_n and Q_{avg}. These results are consistent with previous study [7] in determining the optimum drilling pattern for a circular. Operator B in this case should feel very happy because he/she makes 19% more oil compared to his/her neighbor at the same amount of bid price. Although the area of each pattern (143.5 acre) was set to be the same as well as the number of wells (22) in each section of the reservoir, the number of complete pattern for these two drilling patterns is different. From Fig. 1, the number of complete pattern for the four-spot drilling pattern is nine whereas for the five-spot pattern is only six. Therefore, the four-spot pattern has the bigger aerial sweep efficiency compared to the five-spot pattern.

The difference in terms of total oil production as well as average production per well is less pronounce when injector wells were introduced to the system. This is because in this study, the injector wells were placed at about the same place in each section as if creating a giant five-spot pattern with several producer wells in the middle.

Depending on the initial agreement between these two parties (A and B), they may end up suing each other in the court if one person knows that the other person makes more money than him/her. This paper simply provides a way to solve this dispute if such problem occurs by determining how much of oil that each operator makes from different section in the same reservoir. This paper presents a case where different drilling patterns will result in different amount of oil production given that the area and the number of wells drilled are the same. This BEM formulation can handle a more complicated case than this one since the formulation is capable to give production rate of an individual well. Therefore one could tell the performance of each well present in the reservoir.

Conclusions

The result of this study could be used as a rule of thumb for reservoir engineers in the field when quick approximations need to be made. Although in the real life case, one could never obtained the exact numerical values as presented in the paper, it is believed that the real life case would follows the same general trend as the results of this study. History matching or actual production data matching step needs to be taken as in other reservoir simulation studies.

Other advantage of this BEM formulation is; it gives the production rate of an individual well. This will allow the operator to be able to identify those wells that are performing below expectation and subject them to remedial or work-over operations.

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