SELECTION OF THE OPERATION MODE OF A GAS-LIFT WELLS GROUP BASED ON THE THEORY OF DECISION-MAKING UNDER RISK CONDITIONS

Samira Abbasova Gulbahar Mammadova
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Azerbaijan State Oil and Industrial University
abbasovasamira@mail.ru
gulbahar.mammadova@mail.ru

Abstract

A review of existing methods for assigning and regulating operating modes for groups of wells shows that they do not always allow to obtain satisfactory results, since the complexity and unpredictability of the behavior of the reservoir system and the supply system require approaches that would take into account the uncertainty of conditions.

In this article, when assigning injection modes, a probabilistic decision-making and a decision-making problem are used under conditions of uncertainty for a group of 15 possible wells of the VII formation of the considered field.

The choice of a rational injection strategy under risk conditions is made based on the following considerations: the known probabilities of each strategy result determine the mathematical expectation of each strategy utility. The injection strategy maximizing the expectation of utility is chosen.

Keywords: gas lift wells, working agent consumption, well operation mode, decision making, strategy, risk conditions, uncertainty conditions, matrix

I. Introduction

When controlling the processes of gas lift oil production, the main control parameter is the consumption of the working agent. In this regard, the problem of its rational distribution arises. Usually, the volume of compressed gas is limited, so the task is to distribute it over a group of wells in such a way as to ensure its total consumption minimum.

In practice, there are various methods of assigning operating modes for groups of gas-lift wells [1-5].

A method for operating a group of gas-lift wells, based on increasing for conditions of limited resources of the working agent the working agent consumption in wells with a maximum increase in flow rate is known [6]. An equal amount of gas is pumped into all wells, then the flow rate is measured for each well and the same increment of gas flow is set. After that, the flow rate is measured again, the wells are ranked in descending order of the increase in flow rates. Subsequently, the resources are distributed in such a way that at first the gas flow rate increase in the well is set with the maximum production increment (in the first well) until this increment becomes equal to that measured earlier in the second well. The process is carried out in a number of wells until all gas resources are exhausted. To improve the accuracy of the calculation, after the exhausting gas resources for each well, its flow rate is reduced by the same amount, the oil flow rate is measured for each well and the gas flow rate in the wells with a maximum decrease in flow rate is increased.

In [7], methods for assigning operating modes for groups of gas-lift wells producing non-Newtonian oils are studied.

Work [8] proposes a technique for choosing a certain "compromise" solution for a group of gas-lift wells. The mode is called "compromise" because it is not the best for all wells, however, extending it to a group makes it possible to achieve a total gain in the amount of fluid produced while reducing the flow rate of the injected agent. The choice of the mode was carried out using the apparatus of fuzzy sets theory [9, 10]. With this approach, the lack of information about the processes was modeled by a "fuzzy" (vague) formulation of goals and restrictions imposed on the functioning of the considered group of wells. In addition, the choice of mode was implemented based on the use of a generalized desirability function.

However, the above methods do not always allow to obtain satisfactory results, since the complexity and unpredictability of the behavior of the reservoir system and the supply system require approaches that would take into account the uncertainty of conditions.

Decision making theory, as one of the fundamental sections of the theory of operations research, is precisely aimed at solving such problems.

The content of the decision-making task is to determine the best or acceptable course of action to achieve one or more goals. It is obvious that the application of a scientific approach to the decision-making problem will contribute to the optimization of all management functions and thereby increase their efficiency.

Any decision-making process includes the following elements:

- Target. The need for decision-making is determined by the goal or several goals to be achieved;
- Alternative solutions - different options for achieving goals;
- External environment - the totality of all external factors affecting the outcome of the decision;
- Outcomes of the decision;
- Decision selection rules (decision rules). These rules make it possible to determine the most preferable solution in the sense of the chosen criterion.

In the considered problem of regulating the processes of gas-lift oil production, the goal of making a decision is to minimize the consumption of compressed gas, an alternative is the choice of an injection strategy, due to the choice of a decision-making criterion, the external environment is a combination of various factors affecting the state of the reservoir-well system, the outcome is obtaining a real economy of the injected working agent.

Decision making theory uses various procedures to formalize preferences, that is, to express them in a single quantitative measure. The basis for them is the utility theory [11, 12].

Depending on the conditions of the environment and the degree of awareness, there is the following classification of decision-making problems: deterministic tasks or tasks under conditions of certainty, probabilistic tasks or tasks under risk, tasks under uncertainty [13, 14].

Decision-making under certainty conditions is characterized by an unambiguous or deterministic relationship between decision-making and its outcome. In this direction, decision-making theory is considered from the position of mathematical programming: linear, non-linear, dynamic [11, 12]. These tasks include resource allocation, inventory management, and transport tasks. The application of mathematical programming methods requires the availability of complete and reliable information in the form of a deterministic mathematical model and the need for initial data. Under these conditions, the problem situation is completely defined and there is no need to further define it with a hypothetical situation. This means that all priori probabilities of situations are equal to zero, except for one, which is equal to one. Equality to unity of the probability of a certain situation means that this situation is the only reliable one. Goals under certainty conditions are formally defined and expressed as an objective function and constraints. Preferences are expressed as explicit preference functions. The selection criterion is also known in an explicit formal form. The presence of the above information allows us to build a fully formalized model of the decision-making problem and find the optimal solution.

II. Methods

Decision making under risk. This problem arises when each adopted strategy X_i is associated with a whole set of possible outcomes O_1, O_2,…, O_m with known probabilities $P(O_j/X_i)$. The solution is found using the theory of statistical decisions [16, 17]. Considering random events and processes the incompleteness and unreliability of information in real problems is taken into account in this theory. The description of regularities and behavior of these random objects is made with the help of probabilistic characteristics. The probabilistic characteristics themselves are no longer random, so formal optimization methods can be applied to find the best solution. In this regard, the problems considered in the theory of statistical decisions belong to a particular class of decision making problems under certainty probabilities or decision making under risk.

Formally, the problem model can be represented as a matrix the elements of which l_{ij} are the utilities of the result O_j when using the solution X_i (Table 1). Let conditional probabilities be $P(O_j/X_i)$, j = 1, m; I=1, n

Enter the expected utility for each strategy is entered:

$$E\{u(x_i)\} = \sum_{j=1}^{m} u(O_j, x_i) P(O_j/x_i); \quad i = 1, \dots n \tag{1}$$

Table 1: *The usefulness of the result Oj when using the solution Xi*

$X_i \setminus O_j$	O_1	O_2	…………………	O_m
X_1	L_{11}	L_{12}	…………………	L_{1m}
X_2	L_{21}	L_{22}	…………………	L_{2m}
. . . . . .				
X_n	L_{n1}	L_{n2}	…………………	L_{nm}

The decision rules for determining the optimal strategy X_i are written as follows:

$$E\{u(x_i)\} = \max_{x_k} E\{u(x_k)\} \tag{2}$$

Choice of decisions under uncertainty conditions [13, 15]. These tasks are characterized by great incompleteness and unreliability of information, typical for gas lift oil production processes. The theory of decision making under uncertainty differs in that a large uncertainty of information does not allow to build a strictly formal scheme for finding the optimal solution. The theory presents only methods for narrowing the set of feasible solutions depending on the information uncertainty degree. One of the determining factors here is the external environment (or nature), which may be in one of the unknown states.

Then the mathematical model of the problem under uncertainty is formulated as follows.

There is some matrix with dimensions m×n (Table 1). The elements of this matrix l_{ij} can be considered as the utility of the result O_j when using strategy X_i.

$l_{ij}= (O_j,X_i)$, *j=1,…, m; i=1,…, n.*

Depending on the state of the environment, the result O_j is achieved with probability $P(O_j/X_i,S_k)$.

In addition, the observer does not know the probability distribution $P(S_k)$. Regarding the state of the environment, certain hypotheses can be made. The assumptions about the probabilistic state of the environment are called subjective probabilities $P'(S_k)$, k=1,…K.

If the observer known the value of $P(S_k)$ then we would have a problem of decision making under risk. In fact, the state of the environment is unknown and the probability distribution $P(S_k)$ is also unknown.

The decision is made on the basis of the selection criterion. Selection criteria allows to define a rule by which it is possible to get one optimal solution or narrow the initial set of solutions if there is a lack of information. In any problem, the choice of a solution is assumed. that the set of states of nature $S_1, S_2,\dots,S_n$ implies a complete system of incompatible phenomena, which is directly related to the given task and at the same time is unknown to the person making the decision.

For each of the criteria set out below, it is assumed that a problem of choosing a solution under uncertainty with actions (strategies) $A_1, A_2,\dots, A_m$, environmental states $S_1, S_2,\dots,S_n$, and utility payments u_{ij}; $i=1,\dots,m$; $j=1,\dots, n$ is given.

The main decision-making criteria under conditions of uncertainty are:

- Maximum Wald criterion;
- Savage's minimax risk criterion;
- Criterion of insufficient reason of Laplace;
- Criteria for the indicator of pessimism - Hurwitz's optimism.

The application of these decision-making criteria is considered when choosing the operation modes of a group of gas-lift wells.

Deterministic and indeterminate tasks can be considered extreme cases, such as complete knowledge or complete ignorance of the results of the injection strategy.

Due to its complexity and the interconnectedness of individual wells, deterministic tasks rarely occur or are completely absent in the operation conditions of a group of gas-lift wells.

III. Results

The measurements data of fluid flow rate and compressed gas consumption of 15 gas-lift wells of the VII formation of the considered field for the period 2005-2009 were taken into account.

To assign the injection mode for the entire group of wells as a whole, we apply the above problem with risk (probabilistic problem).

For this purpose, it is convenient to represent problem situations in the form of a matrix, in which each column determines the possible result of obtaining extractions in the liquid Q_j (m^3/day), and each row determines the possible strategy for injecting compressed gas V_j (thousand m^3). The elements of this matrix $l_{ij}=u(O_j,V_i)$ determine the possible results of obtaining selections from these 15 wells (Table 2).

Table 2: *The utility of the result Qj obtained when using the strategy Vj*

V_j		Q_j		
		$Q_1 \leq 50$	Q_2 50÷100	$Q_3 > 100$
V_1	2,3	24	72	121
V_2	2,8	20	76	121
V_3	3,5	46	88	123
V_4	4,0	40	83	121
V_5	4,5	38	82	125
V_6	4,7	32	81	121
V_7	5,0	40	85	126
V_8	5,5	34	87	126
V_9	6,2	40	87	127
V_{10}	6,6	38	85	121
V_{11}	7,0	40	82	115

Here l_{ji} is the utility of the result of obtaining Q_j when using the V_i strategy. The usefulness of the results is expressed as average selections.

Table 3 shows the frequency characteristics of obtaining results Q_j when choosing a strategy Vi.

Table 3: *The frequency response of obtaining the result Qj when choosing a strategy Vi*

V_j	Q_j		
	Q_1	Q_2	Q_3
V_1	2	4	3
V_2	1	6	2
V_3	1	8	4
V_4	2	8	4
V_5	3	9	3
V_6	1	7	5
V_7	1	7	4
V_8	1	9	3
V_9	2	6	2
V_{10}	1	6	3
V_{11}	1	4	3

Table 3 calculates the conditional probabilities

$$P(Q_j/V_i) = \frac{n_j}{N};\ j = 1,m; i = 1,n$$

where N is the total number of wells, N = 15.

The expected utility for each strategy is given

$$E\{u(V_i)\} = \sum_{j=1}^{m} u(O_j, V_i) P(O_j/V_i);\quad i = 1,n \qquad (3)$$

Decision rules for determining the optimal strategy

$$E\{u(V_i)\} = \max_{V_k} E\{u(V_k)\} \qquad (4)$$

We determine $P(Q_j/V_i)$ of the distribution probability (Table 4).

Table 4: *Conditional probabilities of the Qj distribution when choosing a strategy Vi*

V_j	$P(O_j/V_i)$		
	$P(O_1/V_i)$	$P(O_2/V_i)$	$P(O_3/V_i)$
V_1	0,13	0,27	0,20
V_2	0,07	0,40	0,13
V_3	0,07	0,53	0,27
V_4	0,13	0,53	0,27
V_5	0,20	0,60	0,20
V_6	0,07	0,47	0,33
V_7	0,07	0,47	0,27
V_8	0,07	0,60	0,20
V_9	0,13	0,40	0,13
V_{10}	0,07	0,40	0,20
V_{11}	0,07	0,27	0,20

The mathematical expectation of the utility of each strategy $Eu(V_i)$ is calculated:

$Eu(V_1)$ = 24x0,13+72x0,27+121x0,20 = 46,8;

$Eu(V_2)$ = 47,5; $Eu(V_3)$ = 83,1;

$Eu(V_4)$ = 81,9; $Eu(V_5)$ = 81,8;

$Eu(V_6)$ = 80,2; $Eu(V_7)$ =76,8;

$Eu(V_8)$ = 79,8 $Eu(V_9)$ =56,5;

$Eu(V_{10})$ = 60,9 $Eu(V_{11})$ =47,9

Obviously, it is rational to choose strategy V_3, since it maximizes the expectation of utility.

Based on the result obtained, injection mode V = 3,500 m^3 should be assigned for all wells in the group. Then for the group as a whole injection mode will be $\sum V$ = 52 500 m^3, which provides liquid withdrawal $\sum Q$ = 15 x Eu(V$_3$) = 1245 m^3/day. It should be noted that, in fact, the average combined gas flow rate is $\sum V_f \frac{\sum V}{N}$ = 71 000 m^3, and, accordingly, the liquid flow rate is $\sum Q_f = \frac{\sum q}{N}$ = 1226 m^3/day (V, q - respectively, the volumes of injection and withdrawal of fluid for individual wells).

Thus, by determining the injection strategy for a group of gas-lift wells as a whole, it is possible to reduce the consumption of the working agent up to 25% without loss in production.

IV. Discussion

The paper proposes the use of decision theory in conditions of incomplete information, when random factors have a significant impact on the processes occurring during gas lift oil production. In this regard, a methodology has been developed for selecting the operating mode for groups of interacting gas-lift wells based on the criteria of the decision making theory under risk conditions.

The performance of gas-lift wells is presented in the form of a matrix, each column of which determines the possible result of obtaining fluid withdrawals, and each row determines a possible strategy for injecting a working agent. Elements of the matrix determine the usefulness of the result of obtaining when using the strategy, expressed in the form of average values of selections.

The considered problem of regulating the processes of gas-lift oil production for the purpose of making decisions is minimizing the consumption of compressed gas by an alternative to an injection strategy choosing, due to the choice of a decision-making criterion by the external environment. The combination of various factors affecting the state of the reservoir-well system results in real savings in the working agent consumption.

For the group of gas-lift wells under consideration, an injection mode was proposed with a reduction in the working agent consumption up to 25%.

Thus, a decision-making algorithm under conditions of risk and uncertainty can be built on the basis of preliminary formation of options for decisions to be made, identification of risk events in each of them, and, factors of uncertainty, assessment of each of the alternatives according to the presented criteria, selection of the least risky and most acceptable option.

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