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ANALYSIS OF THE RELATIONSHIP BETWEEN THE PERFORMANCE INDICATORS OF THE DEEP-WELL PUMPS AND FACTORS AFFECTING THEIR OPERATION USING THE FUZZY CLUSTER ANALYSIS ALGORITHM

Karazhanova M.K.[1], Efendiyev G.M.[2]
[1]Caspian State University of Technologies and Engineering named after Sh. Yessenov, Aktau, Kazakhstan
[2]Institute of Geology and Geophysics of Azerbaijan National Academy of Sciences, Baku, Azerbaijan

Abstract. The present article is devoted to the results of the information analysis about the operation of the deep-well pumps and the study of the relationship between factors that impact the efficiency of the operation and performance indicators (inter-repair period, the pump delivery rate) using the fuzzy cluster analysis algorithm. A preliminary review of the researches that were collected to date has been performed. As a result of the analysis, the factors that impact the efficiency of the pump in the concerned fields were identified. Attempts to establish a relationship between the input and output variables have not yielded any results due to the presence of various kinds of the uncertainties. In this regard, the data was the subject for the fuzzy cluster analysis, with the help of which an attempt was made to gain the idea of the impact of the noted factors on the performance indicators under the conditions of the uncertainty. As a result the relationship between input and output variables was received, which can be expressed by the fuzzy rules "IF ..., THEN..."

Key words: water content, fluid consumption, inter-repair period, membership function, fuzzy cluster analysis.

Introduction. One of the main tasks of the oil field practice is the evaluation of the impact of the various factors on the performance indicators of the field operations and the acceptance of the right technological decisions. The reliability of the evaluations and accepted decisions is determined by how reliably selected input and output variables, and their values. There often situations when in the presence of the same data, the essentially different results are obtained. To find the specific formulations of these dependencies and parameters that describe them, in particular, the methods of the statistical data processing are used and, finally, the real experimental materials or the results of the field observations are replaced with the obtained dependencies. In accordance with the adopted technology, the law obtained further in terms of the equation of constraints between the influential factors and the performance indicators is transferred to the studied facility. This path is often the source of the false conclusions, since in the most cases the purpose and limitations statement when making the decision due to the multifactorial nature, multicriteriality is fuzzy, in one word, all this requires the use of an corresponding instrument.

Review of the researches for the last few years. In the recent years, the attention of the researches has been attracted by the problems connected with the operation of the deep-well pumps in the complicated conditions, the causes of the failures and the associated decrease in the productivity. The work [1] mainly considers the operation of the sucker-rod pump in the complicated conditions, in particular, discusses the methods to increase the productivity of these pumps. One of the factors complicating the operation of the pumps is the presence of the basic sediments contained in the pumped liquid, which leads to the abrasive wear of the pumping equipment elements, and, ultimately, to the complex accident events, failures. In the reviewed work, an analysis of the data of the number and nature of the pump failures was carried out depending on the category of wells. The main causes of the failures are established; in particular, wear of the plunger pair, the poor manufacturing quality, and the influence of the operational factors. The reliability characteristics were obtained in the form of the dependence of the failure

rate of a plunger-cylinder pair on its operation time and the probability of the failure-free operation, and also the factors that determines the time of the first failure were identified (water content, the presence of the sand and the elements causing corrosion, the pumping speed, suspension depth) [1]. The dependence of the technical resource of the pump on the conditions of the oil production region is obtained: for the low water-producing wells (it is up to 50%), the resource is determined by the wear of the plunger-cylinder pair, which depends on viscosity, resin content, etc., with a high water content – the formation water salinity.

As the result of the analysis, depending on the operating conditions, it was found that the maximum rate of the pump failure is observed in the high rate wells at 5 ... 7 pumping, and in the marginal wells - 5.5 ... 8. If the number of the pumping is more than 6, with its increase, the failure density decreases at any well flow rates. In the marginal wells with a number of pumping of 6 ... 9, the failure density increases. It was also concluded that the operation of the sucker-rod pumps is unreasonable when the viscosity of the produced fluid is less than 100 mm^2/sec. In addition, it was found that the pump-setting depth affects the density of the failures distribution. The failure density increases with the increasing setting depth up to 1100 m of the inserted pumps and up to 650 m of the tubing pumps [1]. The results of these researches under the additions and generalizations can allow the construction of the multi factor models of the reliability characteristics using them in the decision making.

One of the serious problems in this case is the classification and clustering of a large amount of the information. To solve such problems in the fields' development and making the decisions, the fuzzy sets theory has been successfully applied recently. The fuzziness [2] is considered as the situation that occurred due to the physical and linguistic uncertainty. As the author notes, the information on the geological and technical system is limited and does not completely cover the entire system. In addition, the inaccuracy of the measurements and their subsequent interpretation "contribute" to the physical uncertainty of the quantitative evaluations. The linguistic uncertainty of the qualitative parameters is due to the multiplicity and ambiguity of the meanings and relationships in the languages of the specialists and experts [2]. In the noted work, it is believed that the quantitative and qualitative characteristics of the complex geological and technical system are fuzzy. In this regard, the author explores lift methods of the virtual field. According to the work [3], a fuzzy situation can be of three types. In a fuzzy situation of the first type, alternatives from the set Ω are fuzzily described, that is, the properties of the alternatives can only be evaluated at the qualitative level, linguistically, in words. Such evaluation may include the words "good", "bad", "fast", etc. The task of the making the decision in this situation is to choose from the set Ω the best alternative [3, 4].

In the recent years, the serious attention is paid the modeling, which was added to the standard decision analysis approach [5]. The risk analysis based on the Monte Carlo simulation method is a method by which risk and uncertainty are described using the probability distributions. Arbitrary selection in the distributions performed perhaps thousands or more times, allows creating the consistent scenarios. The researches' results of the decision making under the fuzzy conditions in the oil field practice are shown in the works [6–8]. In the work [8], the selection of the operational facilities based on the theory of fuzzy sets is considered. It should be noted that the oil deposit is not a clear and well defined facility, and the screening criteria are a logical generalization of the expert evaluation. The first step is an approximate description of the parameters using the linguistic variables (for example, the collector is evaluated as "poor-porous", "mesoporous" and "highly porous"). At the second step, on the basis of the expert knowledge, the function of belonging to the fuzzy set "operational facility" ("faulty", "very poor", "poor", "satisfactory", "good", "very good", "excellent") is built. In the third step, the rules (R) for the identifying the production facility (PF) are formulated, for example: R1 = "If the difference in the formation depth is insignificant, then the formation will represent a good PF", R2 = "If the geological factors (GF) are good and technological factors (TF) are good, then PF is good, "etc. The advantages of using the theory of fuzzy sets in solving the problems of the control and monitoring of the processes of the exploitation of the oil and gas fields under the conditions of the uncertainty are shown in the

work. The calculation algorithms are given, and the results, obtained under the working with fuzzy values, are shown on the real and hypothetical data. The fuzzy logic and its potential use in solving the problems associated with the petroleum engineering are shown in the works [7,8]. The most successful use of the intelligent systems, especially when solving the technical tasks, was achieved through the use of the various intelligent tools. As shown in the work [8], the expert systems are the artificial intelligence tools that store and implement the expert opinions, methods and rules to achieve the accurate system results. Fuzzy Petroleum Prediction (FPP) was developed as an expert system using the expert knowledge, analysis of the oil wells data and redistribution of the oil fields. The data necessary for its use were selected from the various sources. Five factors were used to predict the oil quality: temperature, pressure, raw oil density, gravity, and gas composition. FPP was used for thirty wells in the Daqing oil field (China).

As noted in the work [9], according to the survey conducted among the oil and gas companies in Ghana, the most managers use the maximax, minimal losses, and the expected value when making the decision under the conditions of the risk and uncertainty. But the quantitative evaluation of the uncertainty is not the goal in itself; eliminating or even reducing uncertainty is also not the goal. It is wrong to assume that the uncertainty is reduced by simply modeling it, and more information is simply required to make the right decision [10]. Rather, the goal is to make the right decision, which in many cases requires the evaluation of the corresponding uncertainties. The oil and gas industry has long lost the sight of this goal, aiming to provide the persons who make the decisions a deeper understanding of the possible results arising from the important decisions [11]. In the woks [12], the methods used to evaluate the underground risks and extensional uncertainty within the life cycle of the exploration and production operations are considered. Although probabilistic methods are necessary for the making the decision, it has been shown that they have limitations that should be understood.

In the work [13], the fuzzy logic is used in the problems of analytical modeling of the enhanced oil recovery methods. Planning the use of the enhanced oil recovery methods is a complex task requiring an integrated approach to its decision. Without optimizing the conditions for choosing the technologies for the implementation at a particular site, it is impossible to fully realize the capabilities of the enhanced oil recovery methods (EORM). To overcome the problems that arise when using the strict limits of the methods applications, it is proposed to use the fuzzy logic and classify the formation facilities as the type of the fuzzy environment, and solving the problem of choosing EORM to the decision making in the fuzzy environment. Using the theory of the fuzzy sets, such the categorical definitions as “very good” or “very bad” can be quantitatively evaluated, which is especially important in choosing the method of the impact [8]. One of the reasons of the degradation factor is the presence of the basic sediments. To choose the most effective method of the protection against the basic sediments, it is necessary to have an idea of the structure and origin of the precipitation, the quantitative composition and the size of their constituent particles. In this regard, the analysis of the basic sediments taken from the wells of the Karakuduk, Karazhanbas and Kumkol fields was performed. The solid inclusions extracted from the samples were studied by the X-ray diffraction method using a general-purpose X-ray diffractometer Rigaku Miniflex-600 [14]. The comprehensive analysis of the chemical composition and the particle size of the basic sediments from the production of the development wells, allows establishing the presence of deposits of different nature and particle sizes. This information can be useful in the development of the appropriate measures to fight the wear of the working units of the pumps [14].

In general, the analysis of the collected researches showed the possibility of solving the problems, in particular, the problems of modeling, decision making, classification of the facilities, etc. using the fuzzy set theory.

Analysis of the various factors impact on the performance indicators of the down hole pumping equipment.

As it is known the main problem under the well performance in the complicated conditions is the degradation factor of the reliability indicators, which in turn influences the technical and economic indicators in general. The number of factors, both geological and technical and

technological, influences the operation of the pumps. Geological factors (the gas, water, deposits of salts, paraffin, basic sediments, etc.) describes first of all the reservoir conditions. Another group of factors are associated with the design of the well or pump (the diameters of the production casing, curvature of the well, units and parts of the pump, etc.). Naturally all the factors can be divided into the factors with the positive and negative impact on the well performance. The water impact on the pump starts almost from the beginning of the well. The appearance of the formation water in oil is one of the main reasons that worsen well performance. The appearance of the formation water leads to the number of complications during operation. The composition of the oil also affects the operation of the pump. Because of the active emulsifiers-asphaltene, as well as resins in the oil content, it is emulsive, which is also contributed by the clay and sand falling from the surface or from the formation. The impact of all the factors that take place is in an ambivalent manner, and therefore, establishing it by the statistical means is difficult, often impossible. In such cases, the use of the theory of fuzzy sets allows establishing the sought-for relationship. To establish the relationship between the pump performance indicators and the relevant factors that describe the well operating conditions, the operating conditions are classified according to the several criteria using a fuzzy cluster analysis program. The characteristics used for the clustering were the water content, fluid rate, content of the basic sediments and productivity factors (the input variables) for the Karazhanbas field was selected, the inter-repair period and the delivery coefficient were taken as the output variables.

The tasks in this simulation attract the interest of the specialists involved in the oil field practice. One of the most important results when studying the operation of the pumps during the field operation is the determination of the delivery coefficient and the inter-repair period. By the implementing of the fuzzy cluster analysis program, homogeneous groups of data clusters were obtained, the results of the noted clustering are given in [4,14].

Table 1 shows the mutual correspondence of the input and output variables.

Table 1. The mutual correspondence of the input and output variables (the inter-repair period, the delivery rate).

Water content	Fluid rate, MPa	Productivity factor, t/day, MPa	Basic sediments, %	Inter-repair period, days.	Delivery rate
low	low	low	high	low	low
			low	middle	middle
high	middle	low	high	high	high
	high	high	high	high	high
		low	middle	high	high

Conclusion. The analysis of the research results has shown that the number of factors impact the performance indicators of the wells; many of them negatively affect the operation of the well equipment and overall performance indicators, and therefore attract the attention of the researchers. As the result of the analysis of the deep well pump failures causes, the factors were established that impact the pump efficiency in the considered fields, which were subjected to the fuzzy cluster analysis, allowed to get an idea of the impact of the noted factors on the performance indicators under the conditions of the uncertainty. As the brief review above shows, the tasks in such formulation attract the interest of the specialists involved in the oil field theory and practice.

The performed cluster analysis allows providing the qualitative evaluation of the impact of the mentioned factors on the delivery rate and the inter-repair period. For example, according to the table 1, if the water content, rate and productivity factor are low, the content of the basic sediments is high, then the inter-repair period and the delivery rate will be low [4,14]. Thus, the results of the analysis allow formulating the fuzzy rules on the principle of "if ... then ..."

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FUZZY CLUSTER ANALYISIS АЛГОРИММІН ПАЙДАЛАНУҒА ҚОЛДАНЫЛҒАН ӨЗДІК ӨЗІНДІҢ ӨЗДІК ӨСІМДІКТЕРІНІҢ ЖӘНЕ ӨЗДІК ФАКТОРЛАРДЫҢ ӨЗДІК КӨРСЕТКІШТЕРІН ТАЛДАУ

Қаражанова М.Қ. - Ш.Есенов атындағы Каспий мемлекеттік технологиялар және инжиниринг университеті, Ақтау, Қазақстан.

Ефендиев Г.М. - Әзірбайжан Ұлттық Ғылым Академиясының Геология және Геофизика Институты, Баку, Әзірбайжан.

Аңдатпа. Мақала ұңғымалық терең сораптардың жұмысы туралы ақпаратты талдау нәтижелеріне және пайдалану тиімділігі мен жұмыс көрсеткіштеріне әсер ететін факторлар (жөндеу аралық кезең, сораптың өнімділігі) арасындағы байланысты анық емес кластерді талдау алгоритмін қолдану арқылы зерттеуге арналған. Бүгінгі күні жиналған зерттеулерге алдын-ала шолу жасалды. Талдау нәтижесінде тиісті учаскелерде сораптың тиімділігіне әсер ететін факторлар анықталды. Кіріс және шығыс айнымалыларының арасындағы

байланысты орнатуға тырысу әр түрлі белгісіздіктердің болуына байланысты нәтиже бермеді. Осыған байланысты, анық емес кластерлік талдау тақырыбы алынды, оның көмегімен белгісіздік жағдайында көрсетілген факторлардың тиімділік көрсеткіштеріне әсері туралы түсінік алуға талпыныс жасалды. Нәтижесінде кіріс және шығыс айнымалылар арасындағы байланыс алынды, оны «ЕГЕР ..., ОНДА ...» деген анық емес ережелермен білдіруге болады.

Түйінді сөздер: судың мөлшері, сұйықтықтың шығыны, жөндеу аралық кезең, мүшелік функциясы, анық емес кластерлік талдау.

АНАЛИЗ ОТНОШЕНИЙ МЕЖДУ ПОКАЗАТЕЛЯМИ ЭФФЕКТИВНОСТИ ГЛУБИННЫХ НАСОСОВ И ФАКТОРОВ, ВЛИЯЮЩИХ НА ИХ РАБОТУ С ИСПОЛЬЗОВАНИЕМ АЛГОРИТМА АНАЛИЗА НЕЧЕТКОГО КЛАСТЕРА

Каражанова М.К. - Каспийский государственный университет технологий и инжиниринга им. Ш. Есенова, Актау, Казахстан.

Эфендиев Г.М. - Национальная Академия Наук Азербайджана, Институт геологии и геофизики, Баку, Азербайджан.

Аннотация. Настоящая статья посвящена результатам информационного анализа о работе глубинных насосов и изучению взаимосвязи между факторами, влияющими на эффективность работы, и показателями производительности (межремонтный период, производительность насоса) используя алгоритм нечеткого кластерного анализа. Предварительный обзор исследований, которые были собраны до настоящего времени, был выполнен. В результате анализа были определены факторы, которые влияют на эффективность насоса в соответствующих областях. Попытки установить взаимосвязь между входными и выходными переменными не дали никаких результатов из-за наличия различных видов неопределенностей. В связи с этим данные были предметом нечеткого кластерного анализа, с помощью которого была предпринята попытка получить представление о влиянии отмеченных факторов на показатели эффективности в условиях неопределенности. В результате была получена связь между входными и выходными переменными, которая может быть выражена нечеткими правилами «ЕСЛИ ..., ТО ...»

Ключевые слова: содержание воды, расход жидкости, межремонтный период, функция принадлежности, анализ нечетких кластеров.