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Some Considerations Concerning Preventive Maintenance Optimization of the Bore-Hole Pumps Valves - Case Study

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Abstract

The paper presents a case study concerning the preventive maintenance optimization of the bore–hole pump valves. The optimum periodicity of preventive maintenance for these valves is determined based on their reliability which was firstly evaluated using their exploitation durabilities. There were analyzed two types of preventive maintenance, at fixed time, and at fixed age respectively. The paper results are embodied in practical charts which can be used for choosing optimal preventive maintenance period of the bore-hole pump valves.

Key words: *bore-hole pump valves, preventive maintenance, reliability, chart*

Introduction

The deep-well pumping system is used for the oil wells exploitation. In our country, this system is used at least for 75 % of the oil wells. The deep-well pumping exploitation is applied in a finally phase, when the natural energy of the stratum decreased and its value is insufficiently for surface oil ascending, or in the case when the artificial lifting can't be done. The efficiency of the deep-well pumping system is influenced by the working life of the pumps and by the consumption of the great wear repair parts (liners, pistons and valves) [1, 3].

The bore-hole pumps working life depends on: the service conditions (the depth of the hole, the aggressiveness of the pumped fluids, the pumping parameters a.s.o.); the bore-hole pumps construction (the type of the pump, the materials used at pumps construction, the quality of the manufacture etc.); the maintenance activities. Regarding the bore-hole pumps operating durability, it can be done the remark that this is determined mainly by the great wear couples which are: liner-piston, pump valve and piston valve. The shut-down of these couples implies the bore-hole pump replacement.

Taking into account of the above statements, it can be concluded that it is necessary to establish a bore-hole pump optimum maintenance program that can reduces at maximum the operating expenses. One of the maintenance strategies that achieve this goal is preventive maintenance based on operational reliability.

The paper aim is to present a general methodology to determine the optimal duration of preventive maintenance as a function of the component replacing cost. This methodology is exemplified for the bore-hole pump valves that are the most often replaced components due to wear. The paper results are embodied in practical charts which can be used for choosing optimal preventive maintenance period of the bore-hole pump valves.

Some considerations on the construction and operation of bore-hole pumps

The considered bore-hole pump in this study is RLAC 2 7/8 x 1 ¾ in x 32c type and it equips the oil-wells of the Boldesti oil field. According A.P.I. Std.11 Ax standard the RLAC 2 7/8 x 1 ¾ in x 32c is a bore-hole pump which is introduced in oil well with the sucker rods. This type has the cylinder with liners and its fastening device is with scoops lies at the superior part of the pump. The external diameter of the tubing is 2 7/8 in., the internal diameter of the pump is 1 ¾ in. and the number of the liners is 32 pieces. The construction and working principle of the bore-pumps is presented in Fig. 1. In this figure, it can be observed the great wear couples of the bore-hole pumps: liner-piston, pump valve and piston valve.

The pump working is characterized by two strokes: one for the upward of the piston and the other for the downward of the piston. At the upstroke of the piston, the pump valve is opened and the piston valve is closed. Thus, the fluid enters in pump and the fluid, which is situated inside of the piston, is pushed up. At the down stroke of the piston, the pump valve is closed and the piston valve is opened. Thus, the fluid enters in piston chamber because of the pressure, which appears in the pump chamber.

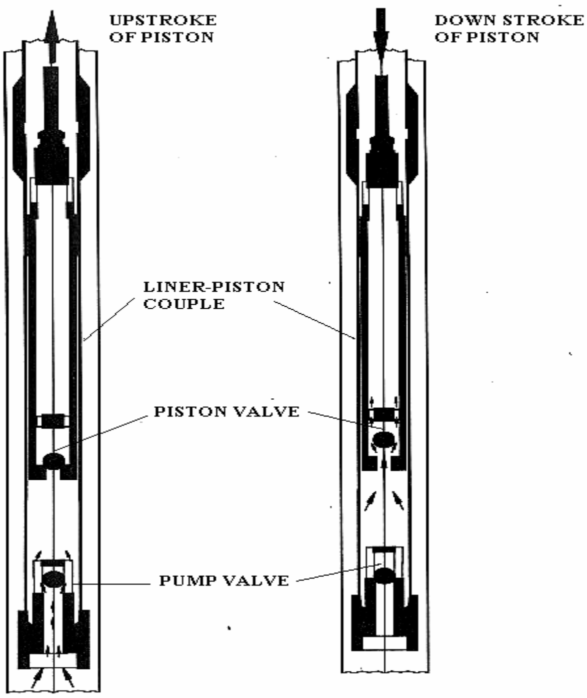

Fig. 1. The construction and the working principle of the bore-hole pumps

Fig. 2. Some examples concerning the working damage of valves

The valves of the pump and of the piston are globe valve type. The component parts of the valves (the valve seat and the globe) are made from anticorrosive alloy steel type 40Cr130 (STAS 3583-87) or X40Cr14 (UNI 6901) respectively X38Cr13 (DIN 17440). The chemical composition (wt.%) of these steels is: C - (0.35...0.44); Si - max 0.6; Mn - max 0.6; Cr - (12,0...14,0) [2,3].

The bore-hole pumps working in different agents which are characterized by the fluid properties (the content of impurities, the corrosiveness etc.). In Fig. 2 there are represented some examples concerning the damage of the valves. From this figure, it can be observed that valves can be failed by erosion and abrasion. The wear of the bore-hole valves implies the decrease of the flow and, so, the durability decreases.

Reliability modeling of the bore–hole pumps valves

The reliability modeling of the great wear couples of the bore-hole pumps was done using the data concerning the operating durability of these. So, there were taken into consideration the data, which were obtained, from 29 bore-hole pumps used in the oil field Boldeşti. These pumps are characterized by the next characteristics concerning the construction and the operating:

- type of the pumps RLAC 2 7/8 x 1 ¾ in x 32c;
- the type of the liners – carbonized;
- the type of the pistons - hard-chromium plating;
- the anchorage depth between 1900 and 2600 m;
- the flow rate in the range of 5…30 m^3/24 hours;
- the double strokes number in the range of 6.5…10.5;
- the working time in the range of 96…1080 hours;
- the type of the agent – hybrid (mixed).

The operating durabilities that were registered for the bore-hole pumps valves are presented in Table 1.

Table 1. Bore-hole pumps valves working durability

Valve type	**Durability [days]**										
Pump valve	36	48	106	107	111	123	167	169	190		
Piston valve	36	44	50	54	75	88	113	123	125	159	190

For modeling the survival processes which are characteristics of bore-hole pumps valves it was used the Weibull partition law with two parameters [4, 5]. The expression of the Weibull law indicators are:

- the probability density:

$$f\left(t,\eta,\beta\right)=\frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}\cdot \mathrm{e}^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{1}$$

- the reliability:

$$R(t)=\mathrm{e}^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{2}$$

- partition function

$$F\left(t\right)=1-\mathrm{e}^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{3}$$

- failure rate

$$z\left(t\right)=\frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \tag{4}$$

- good time functioning average

$$MTBF = \eta \cdot \Gamma\left(\frac{1}{\beta}+1\right) \quad (5)$$

where $\Gamma\left(\frac{1}{\beta}+1\right)$ is first species Euler function

Analytical determination of β and η parameters was done using the method of lowest squares. In Table 2 there are presented the values of Weibull parameters.

Table 2. Parameter values of Weibull law

Valve type	**Weibull law parameter values**			
	β	η	Γ	***MTBF*** [days]
Pump valve	1,688	139	0,89264	124
Piston valve	1,6971	108,2	0,89243	97

Using calculated values of η and β parameters there were plotted the diagrams for reliability (Fig. 3 and Fig. 4), failure rate (Fig. 5) and probability density (Fig. 6). The obtained results concerning the Weibull law parameters and the presented diagrams from Figures 3, 4, 5 and 6 will be used for preventive maintenance periodicity determination.

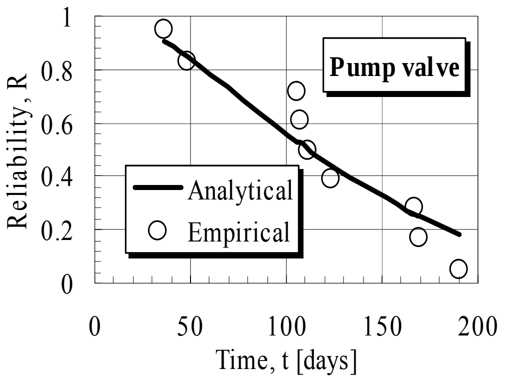

Fig. 3. Analytical and empirical reliability for pump valve

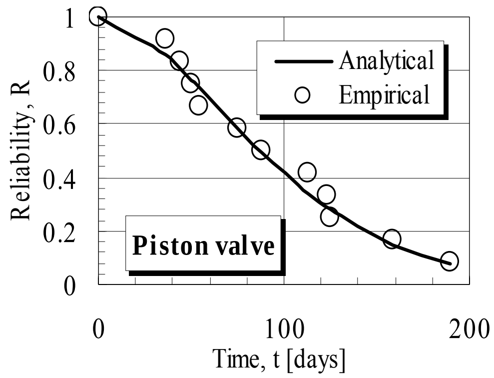

Fig. 4. Analytical and empirical reliability for piston valve

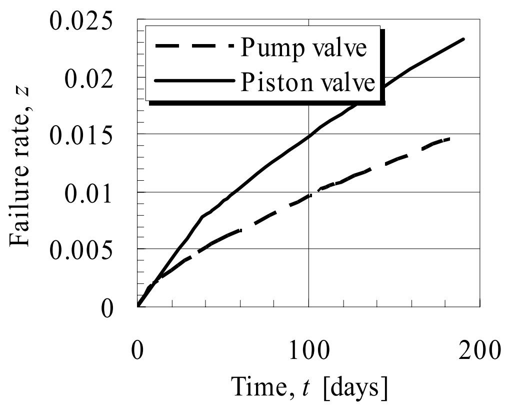

Fig. 5. Failure rate for pump and piston valves

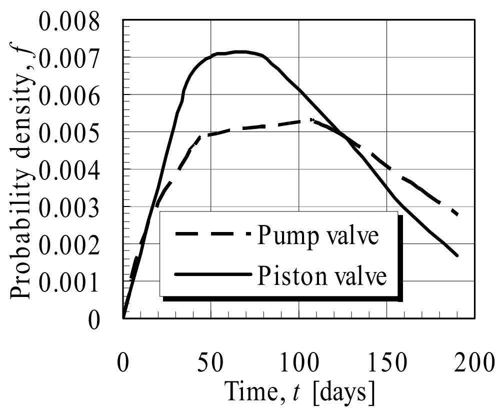

Fig. 6. Probability density for pump and piston valves

Optimal preventive maintenance periodicity determination

One of economical problems that can be solved by knowing of operating reliability is the determination of the optimal preventive maintenance periodicity. This is justified from economic considerations when the following two conditions are met:

- the preventive and planed replacement of a device at fixed date has to cost less than the aleatory replacement made when the device fails;
- the failure rate of the programmed preventive maintenance device has to be increasing.

Further will be used the following notations: c_1 – replacement cost for a good condition device; c_2 – cost of an unexpected failure ($c_2 > c_1$); T – the period when the device attains T age and it is replaced with a new one; $f(t)$ – the probability density; $R(t)$ – the reliability function.

There are two possible maintenance policies, which will be further presented. These policies have to be considered since the product design, and the technical documentation has to contain the maintenance indicators and their determination procedure in addition to reliability indicators [4, 5].

Maintenance at fixed time

In this case all devices are replaced with a periodicity T, whatever their age. In other words, even if at $(T - \varepsilon)$ moment a device was individually replaced, at the fixed time will be replaced all devices again. It presumes being replaced, then new, all devices at the 0 moment and it is calculated mathematical expectation (average) of the device replacement cost at the T moment and for a cost c_1. Then, the probability for having one failure in time T, with $c_1 + c_2$ cost is:

$$\int_0^T F(t_1)R(T-t_1)\mathrm{d}t_1 \tag{6}$$

Probability for two failures with $c_1 + 2c_2$ cost is:

$$\int_0^T F(t_1)\mathrm{d}t_1\int_{t_1}^T F(t_2-t_1)R(T-t_2)\mathrm{d}t_2 \tag{7}$$

Continuing the reasoning, the cost replacement average for a device is:

$$M(c) = c_1 + c_2\left\{\int_0^T F(t_1)R(T-t_1)\mathrm{d}t_1 + 2\int_0^T F(t_1)\mathrm{d}t_1\int_{t_1}^T F(t_2-t_1)R(T-t_2)\mathrm{d}t_2 + \ldots\right\} \tag{8}$$

An optimistic account, which presumes that the global replacements frequency is well chosen, so that never exist more than two consecutive replacements, give a unitary cost equal with:

$$K = c_1 + \left[1 - R(T)\right] c_2 \tag{9}$$

This corresponds at a price for unit time and device:

$$c = \frac{c_1 + \left[1 - R(t)\right] c_2}{T} \tag{10}$$

Deriving relation (10) and equalizing with zero it can be determined the minimum cost which corresponds for an optimum replacement time T^*, then:

$$R\left(T^*\right) + Tf\left(T^*\right) = \frac{c_1 + c_2}{c_2} \tag{11}$$

The T^* value can be obtained using a graphic method which consists in searching minimum value applying relation (11).

For drawing the curves presented in Fig. 7 and Fig. 8 there are used the reliability expressions previous determined. The curves were drawn for a time range of 5000 – 8000 hours, and they can be used for determining of ratio $(c_1 + c_2)/c_2$. Has to be mentioned that the maximum value of this ratio is 2 that corresponding to situation when $c_1 = c_2$, and the minimum value (theoretical) is 1.

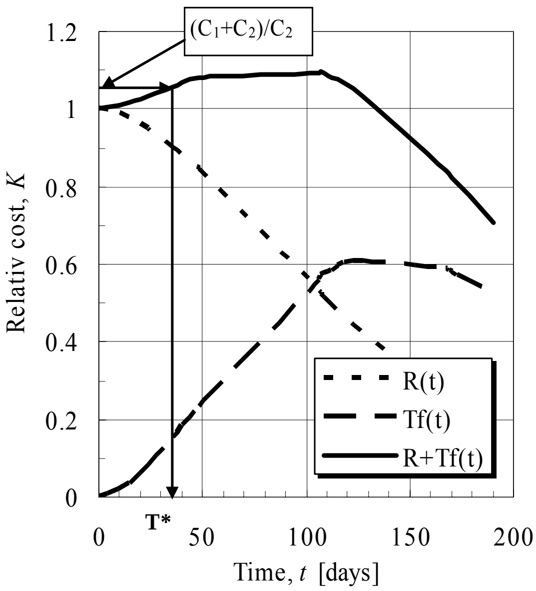

Fig. 7. Maintenance at fixed time for pump valve

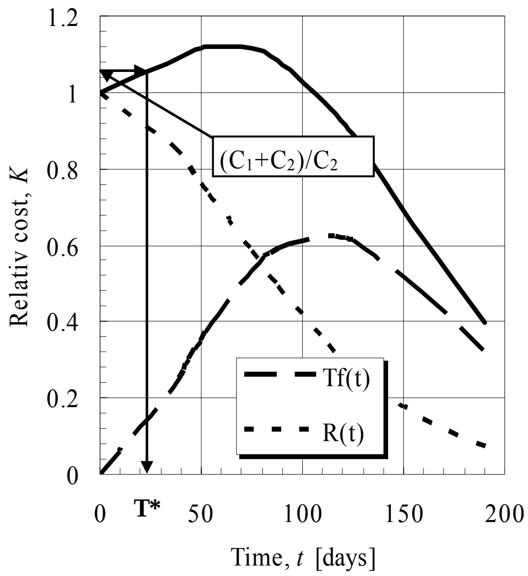

Fig. 8. Maintenance at fixed time for piston valve

Maintenance at fixed age

The second case of maintenance is characterized by a continuous surveillance of the each element (device) age, so this is replaced when attains the age T. From economical reasons, in comparison with the previous case, the differences are the following [4]:

- the number of elements replaced (devices) is reducing, because if one is replaced like being defect, it will not be replaced automatically in a preventive way at a fixed time (that could be immediately after the remedial of defect), but in the moment when attains the age T;
- the device's age has to be known, this implies the existence of a special monitoring;
- replacements at a fixed age are more expensive because they are done only for a single device at a time.

The calculus can be made in a manner that put in evidence the difference between the two types of maintenance. Whether:

$$\frac{1}{M(t)} = \frac{1}{\int_0^T R(t)dt} = \frac{1}{MTBC} + \frac{1}{MTBP} \tag{12}$$

where:

$$MTBC = \frac{\int_0^T R(t)dt}{1 - R(t)} \tag{13}$$

is the average interval between corrective maintenances and

$$MTBP = \frac{\int_0^T R(t)\,dt}{R(t)} \tag{14}$$

is the average interval between preventive maintenances.

The cost per unit time is:

$$K = \frac{c_1}{MTBP} + \frac{c_2}{MTBC} \tag{15}$$

so:

$$K = \frac{c_1 R(T)}{\int_0^T R(t)\,dt} + \frac{c_2 F(T)}{\int_0^T R(t)\,dt} \tag{16}$$

with $F(T) = 1 - R(T)$.

The determination of K value is done, also, in a graphic manner (Fig. 9).

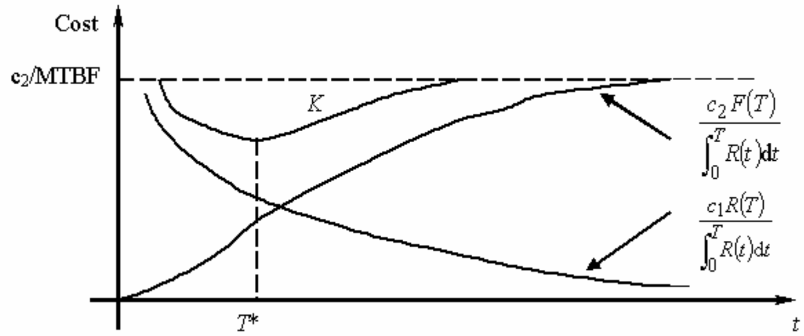

Fig. 9. Graphical determination of the minimum cost for the maintenance at fixed age

In Fig. 10 and Fig. 11 are plotted the curves corresponding on concrete operating conditions of the pump valve and piston valve respectively. Has to be mentioned that in Fig. 9 and Fig. 10 are plotted many curves that corresponding to different values of ratio c_1/c_2, because, as been stated, generally is difficult to establish a unique value of this ratio.

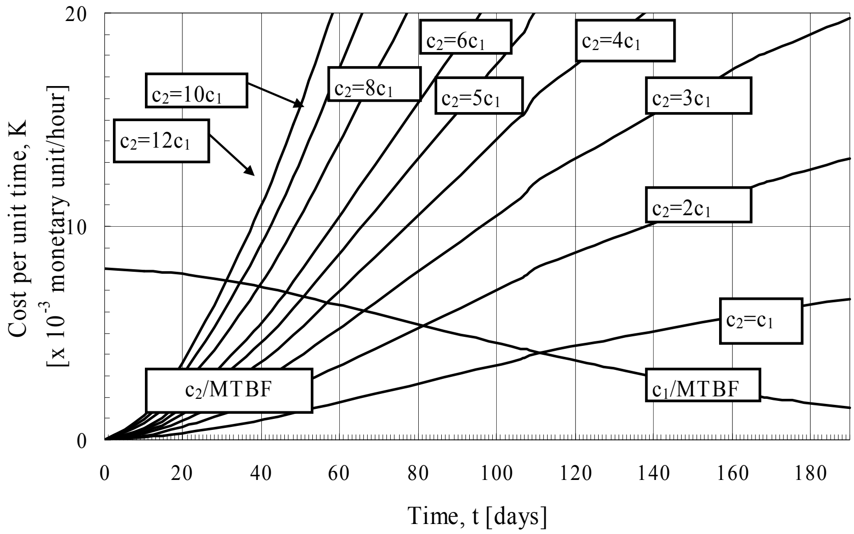

Fig. 10. Graphical determination of minimum cost for maintenance at fixed age for pump valve and for different values of ratio c_2/c_1.

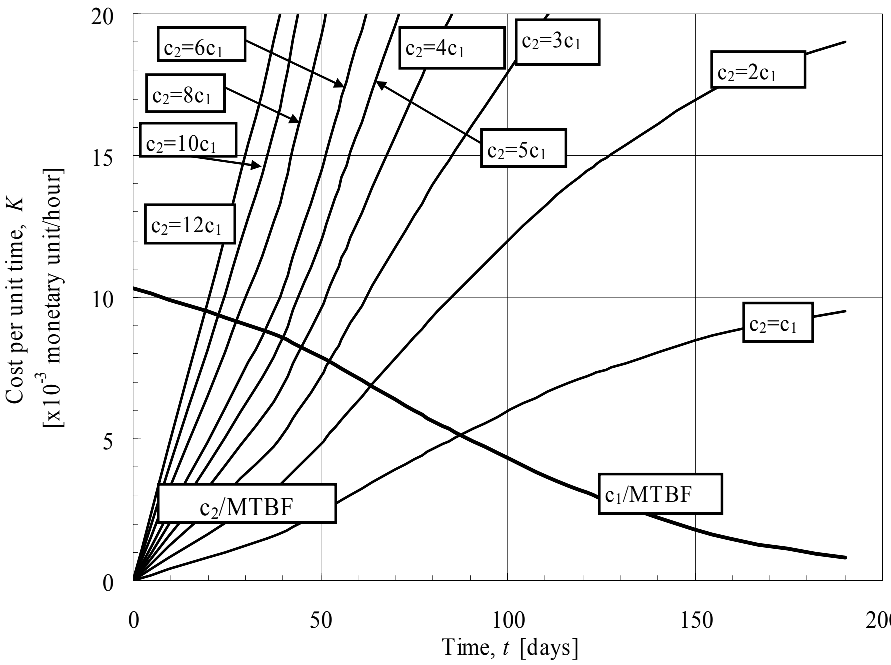

Fig. 11. Graphical determination of minimum cost for maintenance at fixed age for piston valve and for different values of ratio c_2/c_1.

Comparison between maintenance at fixed time and maintenance at fixed age

For comparing the two preventive maintenance variants, at fixed time and fixed age, from the point of view of costs and durations, in Fig. 12 and Fig. 13 there were represented the dependence curves between cost ratio c_2/c_1 and maintenance time.

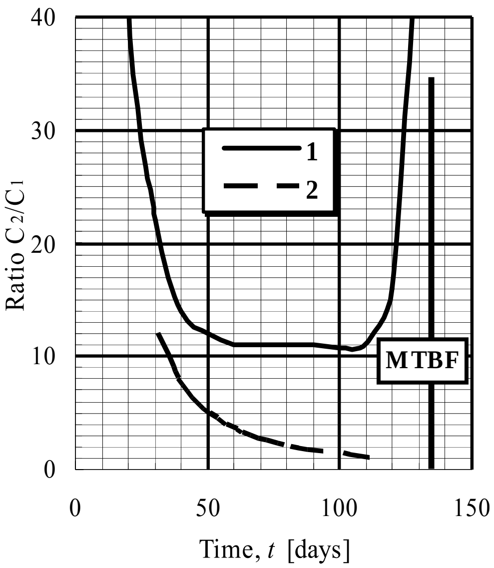

Fig. 13. Comparison between maintenance at fixed time (1) and at fixed age (2) for pump valve

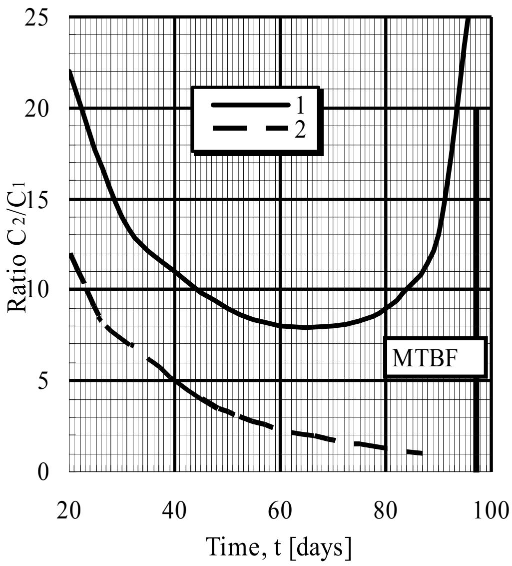

Fig. 14. Comparison between maintenance at fixed time (1) and at fixed age (2) for piston valve

From Fig. 13 it can be observed that for the pump valve when the cost ratio c_2/c_1 has values higher than 11, maintenance at fixed time is recommended while for $c_2/c_1 < 10$ the fixed age maintenance is more economical.

For piston valve (Fig. 14) in the time range of 40 ... 80 days the economical value of the ratio c_2/c_1 is higher than 8 for the fixed time maintenance and smaller than 5 for the fixed age maintenance.

For comparing the same type of preventive maintenance applied to pump and piston valves in Fig. 15 and Fig. 16 there were represented the curves that make the correlation between ratio c_2/c_1 and time.

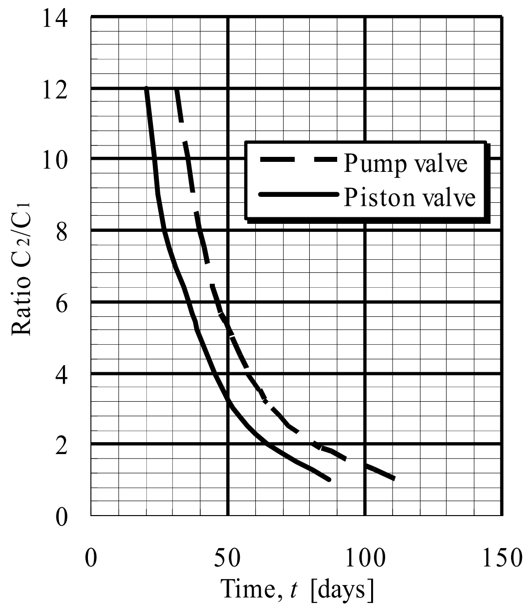

Fig. 15. Comparison between periods and costs of fixed age maintenance

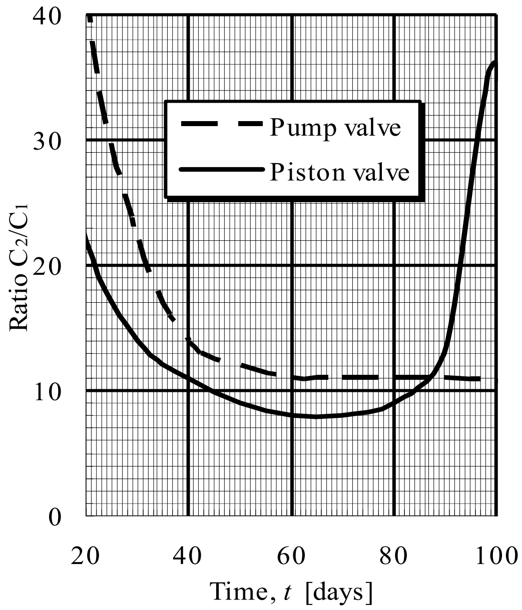

Fig. 16. Comparison between periods and costs of fixed time maintenance

In Fig. 15 it can be observed that for the same ratio c_2/c_1 the biggest replacement periods at fixed time are registered for pump valve, while for piston valve they are the smallest. These results are in accordance with their values of operating reliability.

From Fig. 16 results that the curves intersection take place for values of the ratio c_2/c_1 and for periods at which it can be make replacements for both kinds of valves. Anyway, the minimum values of each curve indicate optimum values of ratios c_2/c_1 for each component.

Conclusions

The main conclusions, which can be detached from this paper, are following:

- paper presents a case study which is imposed to be done for every bore-hole pump type, because of the operating conditions which are different from an oil field to another;
- calculus manner of reliability which was presented in this paper can be used for each type of bore-hole pump and generally for any element (device);
- paper presents a calculus methodology, based on operating data, for determining the optimum preventive maintenance periodicity that can be applied for any element.

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Consideraţii privind optimizarea mentenanţei preventive a supapelor pompelor de extracţie – studiu de caz

Rezumat

Lucrarea prezintă un studiu de caz privind optimizarea mentenanţei preventive pentru supapele pompelor de extracţie din industria petrolieră. Periodicitatea optimă de mentenanţă preventivă pentru aceste supape este determinată pe baza fiabilităţii lor din exploatare. În lucrare sunt analizate două tipuri de mentenanţă preventivă, la dată fixă şi, respectiv, la vârstă fixă. Rezultatele lucrării sunt concretizate în diagrame practice care pot fi folosite la determinarea perioadei optime de mentenanţă preventivă pentru supapele pompelor de adâncime.