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ESTABLISH THE RELIABILITY OF PISTON-CYLINDER COUPLE OF DOWNHOLE PUMPS

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Abstract

Piston-cylinder couple is one of the main compounds of down-hole pumps. Piston-cylinder couple works in severe abrasive and corrosive conditions.
Paper presents experimental tests made in static and dynamic conditions develop to establish wear laws for different piston-cylinder materials at different medium temperatures and pressures.
It is presented the devices used to establish corrosive compound of wear, and the device used for abrasive wear. Were obtained some complex wear laws for each material couple depending of medium, temperature, pressure and composition and of pump work parameters such as the deep in well, pumping velocity et al.
With the wear laws obtained, it was created an original interactive computer program depending on pump type and working parameters, in order to establish the lifetime for piston-cylinder couple. The durability of piston-cylinder couple is very important, because the pump reliability depends on it. The results obtained with the program created were confirmed by industrial practice.
KEY WORDS: *pumps, corrosive wear, piston-cylinder couple, crude oil.*

1. INTRODUCTION

Oil lifting is mainly made by deep-well pumping with piston down-hole pumps. 40% from failures of production wells are caused by pumps failure and pump reliability depends on piston-cylinder and ball valve couple durability. For ceramics ball valve couple pump reliability depends only of piston-cylinder durability. Crude oil contains an important quantity of highly mineralized water, rich gases with a great percent of CO_2, grains of sand from petroliferous bed. Down-hole pumps manipulated by tubing's are exposed to complex wear tips as abrasion, erosion and corrosion. Reliability directly depends of materials behavior of pistons, skirts or long cylinders. Main actual direction to rise working life of down-hole pumps in abrasive and corrosive medium is to use materials with high hardness and resistant at corrosion as hard-chromium plating steel for cylinder or piston, carbonitrided and nitrided cylinder and metallic carbide layers type METCO for pistons in order to resist at heavy duty condition. Paper purpose is to present the methodology used to establish wear laws in order to predict piston-cylinder durability. Because were many factors involved, the experiments were leaded in order to establish each factor influence.

2. EXPERIMENTAL RESULTS

2.1 Corrosion wear in static conditions

From pistons and skirts we prepare samples whose dimensions are presented in figure 1. At cutting and polishing we avoid to pass threw 150^0C, to not modify metallographic structure and the level of internal stress. The inactive faces were covered with synthetic resin, stabile in formation water at maximum testing temperature. After preparing, specimens were weighted with analytical balance with 0,1mg precision. Also were prepared two witness samples to determine the resin water absorption.

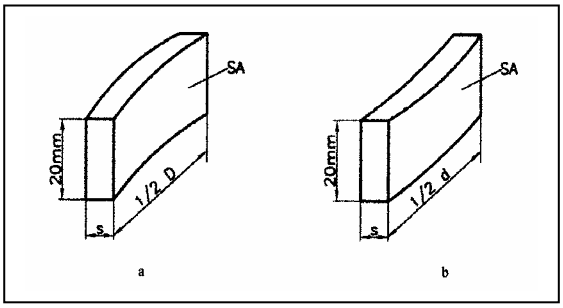


Fig.1: *Sample dimensions for corrosion rate a-cylinder; b-piston; SA-active surface*

Specimens were immersed in formation water putted in nonmetallic glasses. Heating was made in a thermostatic bath. CO_2 barbotage was made with CO_2 cylinder and pressure reducer.

Samples exposed to corrosion in different conditions had the following area:

Piston: A=620mm^2;
Cylinder: chromium-plated A=640mm^2;
carbonitrided A=680mm^2;
nitrided A=620mm^2.

Testing conditions to determine corrosion rate were:

- temperature 20, 30, 40 and 50^{0}C;
- atmospheric pressure with and without CO_2;
- pressure of CO_2 - 2, 3, 4 and 5 MPa.

In figure 2 is shown device diagram for corrosion testing under CO_2 pressure at different temperatures.

Gravimetric indice K_g or corrosion rate v_{cor}, was calculated with relation, [5]:

$$k_g = v_{cor} = \frac{\Delta M}{A \cdot t} \quad \text{,g/m}^2\text{h}$$

were ΔM- mass loss, g;
A- active sample area, mm^2;
t- time, hour.

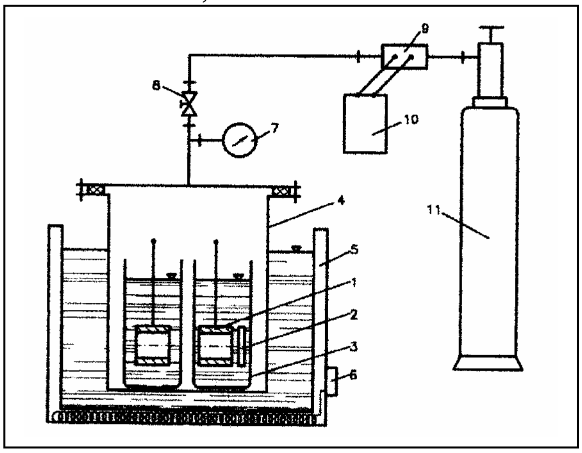


Fig.2: *Static corrosion device diagram 1- sample; 2- active anode; 3- glass with formation water; 4- pressure container; 5- heating bath; 6- thermostat; 7-CO_2 pressure gauge; 8- needle valve; 9- heater; 10- transformer; 11- CO_2 cylinder.*

In table 2 is presented the corrosion rate results for couple piston metal sprayed with chrome plated cylinder, [4].

Table 1. Corrosion rate for couple piston metal sprayed-chrome plated cylinder

Tests conditions		Time , h	Mass loss, mg		Corrosion rate, g/m^{2}h	
Temperature, ^{o}C	Pressure CO_2, bar		Piston	Cylinder	Piston	Cylinder
20	-	135	4,4	2,5	0,053	0,029
20	barbotage	135	4,7	2,6	0,056	0,030
20	20	135	4,2	2,9	0,051	0,034
20	40	135	4,4	3,0	0,053	0,035
30	-	135	7,7	4,3	0,092	0,050
30	barbotage	135	7,9	4,6	0,094	0,053
30	20	135	8,0	4,8	0,096	0,056
30	30	60	3,7	2,3	0,099	0,060
30	40	135	7,8	4,9	0,093	0,057
40	-	69	4,1	2,5	0,096	0,057
40	barbotage	69	4,4	2,9	0,102	0,066
40	20	69	4,1	2,6	0,096	0,059
40	30	67	4,0	2,7	0,096	0,063
40	40	69	4,3	2,9	0,100	0,066
40	50	67	4,2	3,0	0,101	0,070
50	-	70	4,5	2,7	0,104	0,060
50	barbotage	70	4,8	3,1	0,111	0,069
50	20	70	4,2	2,7	0,097	0,060
50	30	50	2,8	3,1	0,090	0,053
50	40	70	4,4	2,9	0,101	0,065
50	50	50	3,0	1,9	0,097	0,053

Similar results were obtained for couples piston metal sprayed- cylinder carbonitrided and nitrided, [3].

2.2 Wear of piston- cylinder couples

Wear abrasion process was research on a testing machine designed and completed for that purpose. In figure 3 is presented cinematic diagram of the device.

On vertical rod *1* is fixed the sample type piston *2*. Sample type skirt *3*, slotted is tighten on piston with a flexible cable *4*, tensioned with weight set *5*. Alternative movement of the piston is provided by crank and connecting-rod assembly *6*, moved by electric motor *11*. Piston-cylinder system is completely immersed in formation water from tank *9*. To maintain in suspension sand, we have a punched plate *10*.

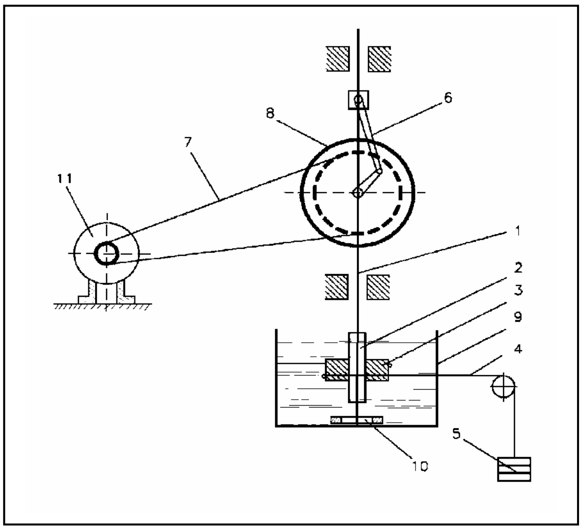


Fig.3: *Cinematic diagram of the device*

For wear tests it was used formation water with 3% sand from down-hole pumps with grain size smaller than 63 μm.

Testing conditions were:

- cable load, 50N;
- double stroke per. min., 54;
- temperature, 20^0C;
- barbotage of CO_2;

In table 2 are presented the piston-cylinder wear results with CO_2 barbotage, [3].

To fix experimental load was fixed the pressure between piston and cylinder in real conditions, for a pump and a crude oil type [2]:

$$p = \frac{2290 \cdot \mu \cdot v_m \cdot N}{f \cdot j_r}, \text{ N/m}^2$$

were: μ is dynamic fluid viscosity, Pa.s;

v_m – piston average speed, m/s;

$v_m = S.n/30$

S- piston stroke, m;

n- double stroke per. min.;

f – friction coefficient;

N – load, N;

j_r – radial clearance, μm.

Table 1. Piston-skirt wear

Material couple		Wear, mg							
		Piston				Skirt			
Piston	Skirt	15'	30'	45'	60'	15'	30'	45'	60'
Metal Spray-ed	Chro-mium plated	5,3	8,6	10,8	12,2	6,1	8,3	9,5	10,2
Metal Spray-ed	Carbo-nitrid-ed	6,4	8,3	9,4	13,0	9,4	12,6	15,3	19,2
Metal Spray-ed	Nitri-ded	6,1	7,9	8,5	9,1	6,8	9,4	12,3	14,5

Piston specimens presented in figure 4 were machined from real pistons.

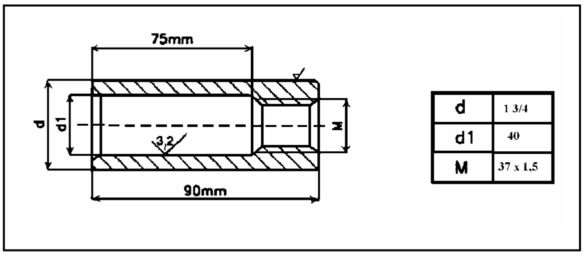
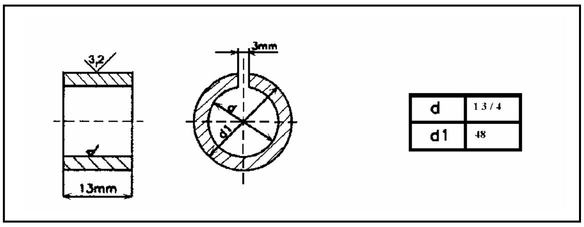


Fig. 4: *Piston specimen*



Cylinder samples presented in figure 5 were machined from real cylinders.

Fig. 5*: Cylinder specimen*

2.3 Wear laws

Analyzing corrosion experimental results with CurveExpert program was establish a correlation between corrosion rate and temperature:

$$v_{cor} = a_{p,c} - b_{p,c} \cdot e^{-c_{p,c} \cdot t^{d_{p,c}}} \text{, g/m}^2\text{h}$$

were: $a_{p,c}$, $b_{p,c}$, $c_{p,c}$, $d_{p,c}$ are coefficients depending of piston (*p)* and cylinder (*c)* materials couple and of testing conditions [4].

In figure 6 is presented the variation of corrosion rate versus temperature for metal sprayed piston with chromium plated cylinder.

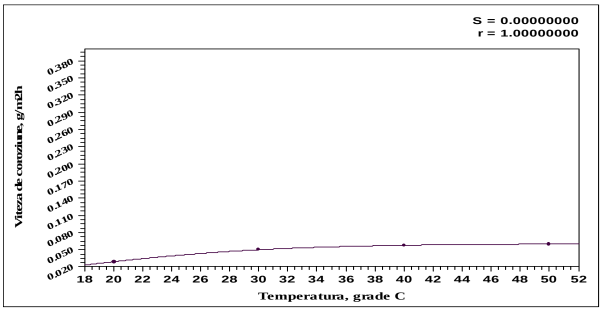


Fig. 6: *Corrosion rate versus temperature*

With CO_2 pressure was estabilish a correlation as:

$$v_{cor} = a_{p,c} + b_{p,c} \cdot p + c_{p,c} \cdot p^2 + d_{p,c} \cdot p^3 + e_{p,c} \cdot p^4 \text{,g/m}^2\text{h}$$

were, $a_{p,c}$, $b_{p,c}$, $c_{p,c}$, $d_{p,c}$, $e_{p,c}$ are coefficients depending of piston (*p)* and cylinder (*c)* materials couple and of testing conditions [4].

In figure 7 is presented the variation of corrosion rate versus CO_2 pressure for metal sprayed piston with chromium plated cylinder.

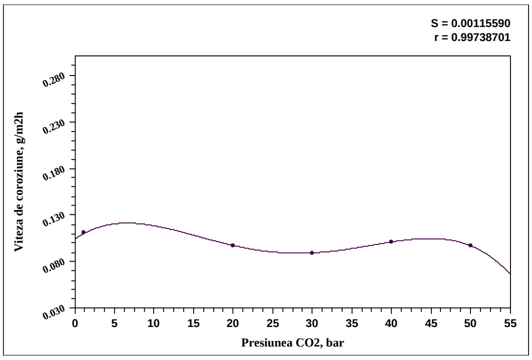


Fig. 7: *Corrosion rate versus CO_2 pressure*

Analyzing results for wear with DataFit program was establish the relation:

$$u = a_{p,c} \cdot x + b_{p,c}$$

were, u is wear, mg;

x- time, min.;

$a_{p,c}$, $b_{p,c}$ - coefficients depending of piston (*p)* and cylinder (*c)* materials couple and of testing conditions [4]

In figure 8 is presented the variation of wear versus time for metal sprayed piston with chromium plated cylinder, [4].

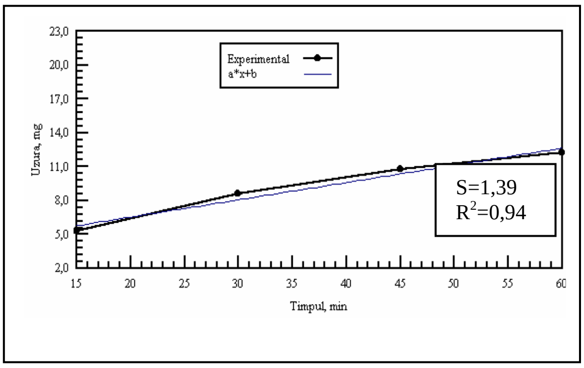


Fig.8: *Piston-cylinder wear*

3. PISTON-CYLINDER DURABILITY

To obtain optimum pump efficiency, the cumulate linear wear of piston and cylinder must not pass a certain value:

$$h_{max} \leq j_{max} - j_i \text{ ,mm}$$

were: h_{max} is cumulate linear wear, mm;

j_{max}- maximum clearance between piston and cylinder, mm;

j_i- initial clearance, mm.

$$h_{max} = h_p + h_c \quad \text{, mm}$$

were: h_p - linear piston wear,

$$h_p = \frac{u_p}{\rho_p \cdot A_{fp}} \cdot \frac{v_{m,pr}}{v_{m,pex}} \cdot 10^{-3} \text{ , mm}$$

h_c – linear cylinder wear,

$$h_c = \frac{u_c}{\rho_c \cdot A_{fc}} \cdot \frac{v_{m,pr}}{v_{m,pex}} \cdot 10^{-3} \text{ , mm}$$

u_p, u_c – gravimetric piston and cylinder wear, mg;

ρ_p, ρ_c – surface piston, cylinder density, kg/m^3;

A_{fp}, A_{fc} – friction area for piston, cylinder, m^2;

$A_{fp} = \pi \cdot d_{Np} \cdot l_p$;

$A_{fc} = \pi \cdot D_{Nc} \cdot (l_p + C_r)$;

$d_{Np} = D_{Nc}$ – nominal diameter for piston, cylinder, mm;

$v_{m,pr}$- average pump piston speed,

$$v_{m,pr} = \frac{C_r \cdot n}{30} \text{, m/s;}$$

$v_{m,pex}$ – average experimental piston speed,

$$v_{m,pex} = \frac{C_{ex} \cdot n_{ex}}{30} \text{,m/s;}$$

C_r – effective piston stroke, [1], $C_r = k \cdot C - \lambda$, m;

k – overload coefficient, [1]

$$k = 1 + \frac{2{,}27 \cdot (H \cdot n)^2}{10^{10}}$$

λ - rod string extension, [1],

$\lambda = H^2 \cdot \alpha$, m;

α - extension coefficient, m/m^2;

H – depth of plunger, m;

n, n_{ex} – double stroke per. min. at pumping unit, respective experimental;

l_p – piston working length, m;

C – surface stroke, m.

$$h_{max} = \frac{u_p}{\rho_p \cdot A_{fp}} \cdot \frac{C_r \cdot n}{C_{ex} \cdot n_{ex}} \cdot 10^{-3} + \frac{u_c}{\rho_c \cdot A_{fc}} \cdot \frac{C_r \cdot n}{C_{ex} \cdot n_{ex}} \cdot 10^{-3}, \text{mm}$$

Replacing u_p and u_c and notating a_{pij}, b_{pij}- coefficients for piston i in couple with cylinder j, and a_{cji}, b_{cji}- coefficients for cylinder j in couple with piston i, for time life x was obtained the following relation:

$$x = \frac{\pi \cdot d_N \cdot l_p \cdot \rho_{pi} \cdot h_{max} \cdot \frac{C_{ex} \cdot n_{ex}}{C_r \cdot n} \cdot 10^3 - \left[b_{pij} + \frac{b_{cji}}{\frac{\rho_{cj}}{\rho_{pi}} \cdot \left(1 + \frac{C_r}{l_p}\right)} \right]}{\left[a_{pij} + \frac{a_{cji}}{\frac{\rho_{cj}}{\rho_{pi}} \cdot \left(1 + \frac{C_r}{l_p}\right)} \right]}$$

To establish j_{max} was used the condition of minimum surface efficiency, η=0,65 [5].

Piston-cylinder efficiency it is, [4]:

$$\eta_{p-c} = \frac{\eta}{\eta_c \cdot \eta_{sm} \cdot \eta_{sf}} = 0{,}9483283$$

were η_c=0,96735 is strokes rapport;

η_{sm}=0,746 – traveling valve efficiency;

η_{sf}=0,9498- standing valve efficiency.

From pump rate leakage relation, [5]:

$$Q_p = 4{,}97 \cdot 10^{-4} \cdot \frac{\pi \cdot d_N \cdot H}{\nu \cdot l_p} \cdot j_{max}^{\;3}, \quad \text{m}^3/24\text{h}$$

were ν is cinematic viscosity, St.

According to test condition for a corrosive and abrasive medium, initial clearance it is recommended, j_i=50µm and thus h_{max}=97µm.

In table 3 it is presented the time life for piston-cylinder couple at 20^{0}C and 0,11MPa partial pressure of CO_2. Te results obtained show that the best couple is metal sprayed metal land chrome plated cylinder.

Table 3. Durability for piston-cylinder couple

Materials couple		Durability, days	R^2
Piston	Cylinder		
Metal sprayed	Chrome plated	161,1	0,9318
Metal sprayed	Carbonitrided	133,8	0,9449
Metal sprayed	Nitrided	141,3	0,9142

In order to consider the temperature and CO_2 pressure influence above the piston-cylinder durability it was definite the gravimetric wear index for the piston i which work with cylinder j as:

$K_{upij} = v_{upij} \cdot 10^{-3} / \cdot A_{pex.}$, g/m^2·h

were v_{upij} is gravimetric wear rate for piston i which work with cylinder j, mg/m^{2}h;

$A_{pex.}$- piston area at wear tests.

In the same way was definite K_{ucji}.

Observing that $v_{corpij}/ K_{upij} = m_{pij}$=ct.

and

$v_{corcji}/ K_{ucji} = m_{cji}$=ct.

were $v_{corpij,\, corcji}$ is the corrosion rate depending on temperature and CO_2 pressure for piston i whom work with cylinder j, respective for cylinder i which work with piston j.

It was obtained the correlation between wear rate and corrosion rate:

$v_{upij,ucji} = v_{corpij,\, corcji}(\text{t}, p_{CO2}) \cdot A_{pex,\, cex} \cdot 10^3 / (m_{pij,cji} \cdot 60)$

Because wear rate represents wear derivative with time, the $a_{pij,\, cji}$ coefficients from wear law obtained at experimental tests are:

$a_{pij,\, cji} = v_{corpij,\, corcji}(\text{t}, p_{CO2}) \cdot A_{pex,\, cex} \cdot 10^3 / (m_{pij,cji} \cdot 60)$ [mg/min]

In VisualFoxPro programming language was created an original computer program in order to evaluate lifetime for different piston-cylinder material couple and for different working conditions. In figure 9 is presented the program window simulation.

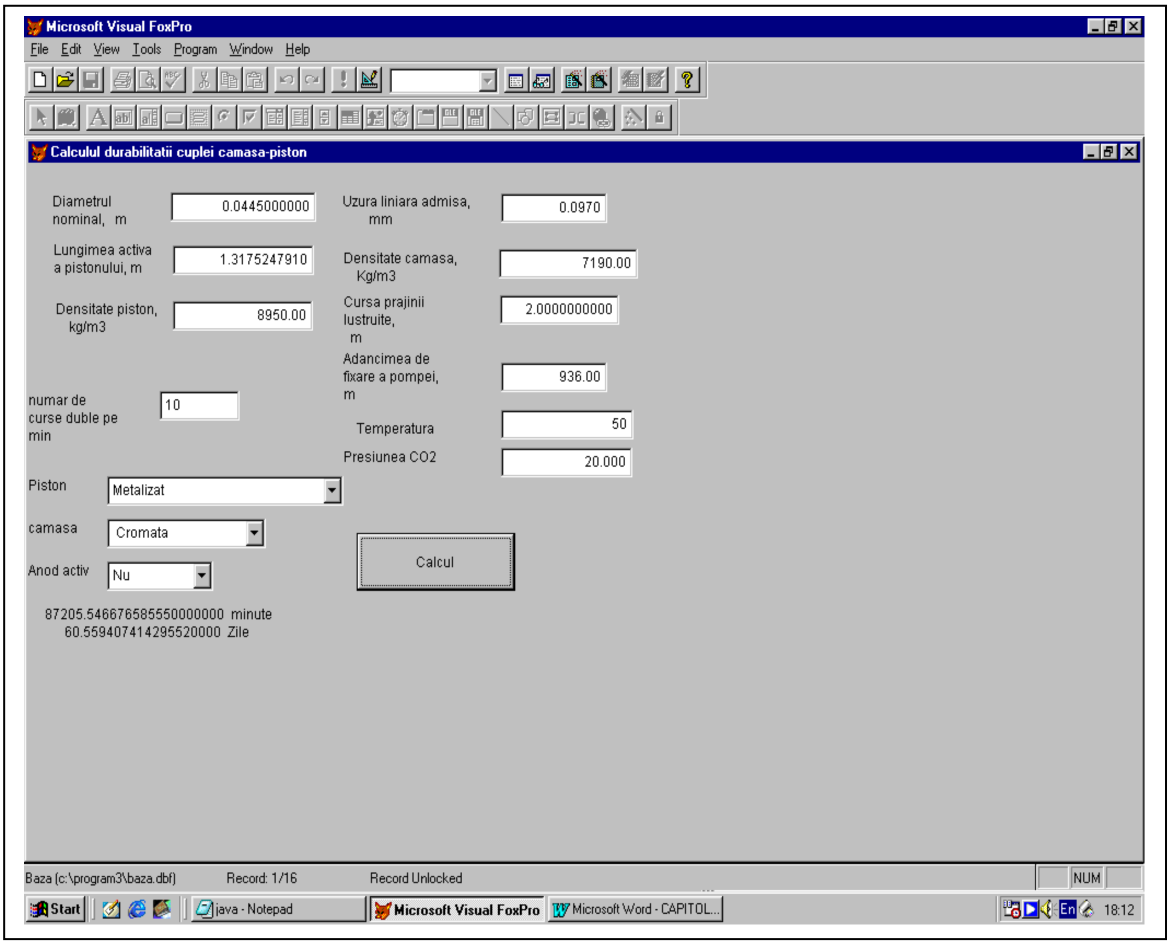


Fig. 9*: Durability calculus window program simulation*

4. CONCLUSIONS

Experimental tests establish that wear rise with temperature. With CO_2 pressure the influence above wear is different depending on the CO_2 pressure value. Because at CO_2 pressure tests was used only CO_2 gas the CO_2 pressure value is the same with partial pressure of CO_2. The maximum corrosion rate was obtained for 8…10 bar CO_2 pressure when the conductivity of tested formation water was maximum.

Computer program created permits evaluation of lifetime for pump piston-cylinder couples in different working conditions.

Lifetime evaluation error is smaller than 12%, and program accuracy was confirmed by industrial practice in oil fields.

5. REFERENCES

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