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DETERMINATION OF PRESSURE IN THE PLUNGER DURING THE OPERATION OF OIL WELLS BY SUBMERSIBLE PUMPS

Yuldoshova Zarnigor Sayfullo qizi*

*Doctoral Student,
Samarkand State Institute of Architecture and Construction,
UZBEKISTAN
Email id: z.yuldoshova@mail.ru

ABSTRACT

The article discusses the definition of pressure on the plunger during the operation of oil wells with deep pumps. The resulting formulas are of interest, both for calculated purposes and to substantiate the methods of experimental research. Determination of the pressure on the plunger is of interest both for design purposes for the design and operation of oil wells and for substantiating the experimental research methodology. In the mathematical modelling of the process, generally accepted assumptions are used regarding the fluid and its motion.

KEYWORDS: *Pre-image and Laplace transform, Oil wells, Pressure on a plunger, Velocity liquid.*

INTRODUCTION

During the operation of oil wells with downhole pumps with a hydraulic seal, due to the variability of the plunger speed, the movement of fluid in the gap between the plunger and the cylinder of the downhole pump is unsteady, which is reflected in the total pressure on the plunger and on the fluid leakage through the gap.

Relevance and Problem Statement Determination of the pressure on the plunger is of interest both for design purposes for the design and operation of oil wells and for substantiating the experimental research methodology. In the mathematical modelling of the process, generally accepted assumptions are used regarding the fluid and its motion [1,2,3]. During pumping, the change in pressure on the plunger is due to the inertia of the liquid and the total pressure on the plunger will be:

$$p(t) = \Delta p(t) + (L-h)\gamma + p_0, \qquad (1)$$

Where $\Delta p(t) -$ pressure loss during unsteady movement of a viscous fluid in an annular riser pipe; $p_0 -$ wellhead pressure; $L -$ the height of the liquid column being lifted; $h -$ immersion depth of the deep-well pump; $\gamma -$ the specific gravity of the liquid. In the practice of operating oil wells with deep pumps $\alpha = r_2 / R > 0.2$ [1, 2] for such a case, the radial gap between the pipe and the rod column can be considered as a flat pipe [3]. In a non-stationary laminar flow of a viscous fluid in a lifting tube, the velocity of the fluid can be determined from the equation

$$\rho \frac{\partial v}{\partial t} = \mu \frac{\partial^2 v}{\partial y^2} + \frac{\Delta p}{L}, \quad (0 < y < l), \tag{2}$$

$$\begin{aligned} &v(y,0) = 0, \quad (0 \le y \le l); \\ &v(0,t) = v_0(t), \quad v(l,t) = 0, \quad (0 \le t \le T), \end{aligned} \tag{3}$$

Where $\rho, \mu -$ density and dynamic viscosity of the liquid; T - the period of one cycle of plunger movement; $r_2 -$ radius of the rod; $R -$ lifting tube radius; $l = R - r_2$. Equation is used to define $\Delta p(t)$

$$Q = \pi(r_1^2 - r_2^2)v_0(t) = 2\pi \int_0^l (y + r_2)v(y,t)dt, \tag{4}$$

Where $r_1 -$ plunger radius, $Q -$ fluid consumption Relations (2) - (4) expresses the mathematical model of the process under study;

METHODS

We introduce the following new dimensionless quantities

$$\bar{t} = \frac{t}{t_x}, \quad x = \frac{y}{l}, \; \bar{v}(\bar{t}) = \frac{v(t)}{v_c}, \; \bar{v}_0(\bar{t}) = \frac{v_0(t)}{v_c}, \; \bar{q}(\bar{t}) = \frac{l^2}{\mu v_c} \frac{\Delta p}{L},$$

$\bar{T} = \dfrac{T}{t_x}$, $v_c -$ the average speed of the suspension point of the rods, $t_x = \rho l^2 / \mu$.

Then, in dimensionless variables, we have the equation

$$\frac{\partial \bar{v}}{\partial \bar{t}} = \frac{\partial^2 \bar{v}}{\partial x^2} + \bar{q}(\bar{t}), \quad (0 < x < 1) \tag{5}$$

Boundary conditions (3) and balance ratio (4) take the form:

$$\begin{aligned} &\bar{v}(x,0) = 0, \quad (0 \le x \le 1); \\ &\bar{v}(0,\bar{t}) = \bar{v}_0(\bar{t}), \quad \bar{v}(1,\bar{t}) = 0, \quad (\bar{t} > 0). \end{aligned} \tag{6}$$

$$\frac{r_1^2-r_2^2}{2l^2}\overline{v}_0(\overline{t})=\int_0^1 (x+\frac{r_2}{l})\overline{v}(x,\overline{t})dx. \qquad (7)$$

To solve the problem, applying the integral Laplace transform

$$\tilde{v}(x,s)=\int_0^{+\infty} e^{-st}\overline{v}(x,\overline{t})d\overline{t},\quad \tilde{v}_0(s)=\int_0^{+\infty} e^{-st}\overline{v}_0(\overline{t})d\overline{t},\quad \tilde{q}(s)=\int_0^{+\infty} e^{-st}\overline{q}(\overline{t})d\overline{t},$$

We get $\tilde{v}(x,s)=\tilde{v}_0(s)\dfrac{shw(1-x)}{shw}+\dfrac{\tilde{q}(s)}{s}\cdot\left(1-\dfrac{shw(1-x)}{shw}-\dfrac{shwx}{shw}\right),$ where $w=\sqrt{s}.$

Substituting the expression for $\tilde{v}(x,s)$ in the image of the relation (7) we get

$$\tilde{q}(s)=\frac{l}{l+2r_2}\cdot s\tilde{v}_0(s)\cdot f(w), \qquad (8)$$

Where

$$f(w)=\frac{\varphi(w)}{\psi(w)},\ \varphi(w)=1-\frac{shw}{w}+\frac{r_2}{l}(1-chw)+\frac{r_1^2-r_2^2}{2l^2}wshw;\ \psi(w)=1-chw+\frac{w}{2}shw.$$

Using the methods of the theory of functions of a complex variable we decompose the function $f(w)$ into a series:

$$f(w)=\frac{4f_0}{w^2}+4\sum_{k=1}^{\infty}\left[\frac{1}{w^2+a_k^2}+\frac{w_k\varphi_k}{\psi_k(w^2+w_k^2)}\right]=\frac{4f_0}{s}+4\sum_{k=1}^{\infty}\left[\frac{1}{s+a_k^2}+\frac{w_k\varphi_k}{\psi_k(s+w_k^2)}\right].$$

Here $w=w_k$ the roots of the equation $\psi(w)=0$:

1) $w=w_k=\pm ia_k=\pm 2k\pi i,\ a_k=2k\pi,\ k=1,2,\ldots;$

2) $w=w_k=\pm 2z_k,\ k=1,2,\ldots,$ z_k- Positive roots of the equation $tgz=z.$

$$f_0=\frac{3}{l^2}\left(r_1^2-r_2^2-r_2 l\right)-1,\ \psi_k=w_k\cos w_k-\sin w_k,$$

$$\phi_k=1-\frac{\sin w_k}{w_k}+\frac{r_2}{l}(1-\cos w_k)+\frac{r_1^2-r_2^2}{2l^2}w_k\sin w_k.$$

The original $\Phi(\overline{t})$ corresponding to the $f(w)$ has the form

$$\Phi(\overline{t})=4f_0+4\sum_{k=1}^{\infty}\left(e^{-a_k^2\overline{t}}+\frac{w_k\phi_k}{\psi_k}e^{-w_k^2\overline{t}}\right). \qquad (9)$$

From (8) and (9), using the composition theorem of the operational calculus, we find the formula for: $\overline{q}(\overline{t})$:

$$\overline{q}(\overline{t}) = \frac{l}{l+2r} \cdot \int_0^{\overline{t}} \overline{v}_0^{'}(\tau)\Phi(\tau)d\tau \qquad (10)$$

RESULTS AND DISCUSSION

Formula (10) allows you to determine the pressure drop at a given speed of the plunger. Following [1], the speed of movement of the plunger $v_0(t)$ during one cycle of its movement $0 \le t \le T$ can be taken as:

$$v_0(t) = \frac{48v_c}{\pi^3} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^3} \sin\frac{2\pi(2n-1)t}{T} \qquad (11)$$

The pressure loss in the riser is determined by substituting (10) into the formula $\Delta p(t) = \mu v_c L\overline{q}(\overline{t})/l^2$, the total pressure is found by the formula (1).

Using the obtained formulas, numerical experiments were performed using the following initial data:

$L-h = 1000\,м$; $v_c = 0{,}60\,м/c$; $T = 20\,c$, $R = 0{,}030\ м$, $r_1 = 0{,}028\,м$, $r_2 = 0{,}010\,м$, $p_0 = 10^5\,Pa$. Fig. 1 shows the graphs of the total pressure on the plunger versus time for three types of oil: 1) $\mu = 0.04\,Па\cdot c$, $\rho = 750\,кг/м^3$; 2) $\mu = 0.07\,Па\cdot c$, $\rho = 800\,кг/м^3$; 3) $\mu = 0.10\,Па\cdot c$, $\rho = 900\,кг/м^3$ It can be seen from the graphs that the profiles of the total pressure differ significantly in the initial period and the period of the end of the descent acceleration, as well as at the moment of stopping the plunger.

CONCLUSION

The resulting formulas can be used in the design and operation of oil wells with deep pumps with hydraulic shutters. They allow you to explore the effect of viscosity and oil density for full pressure on the plunger.

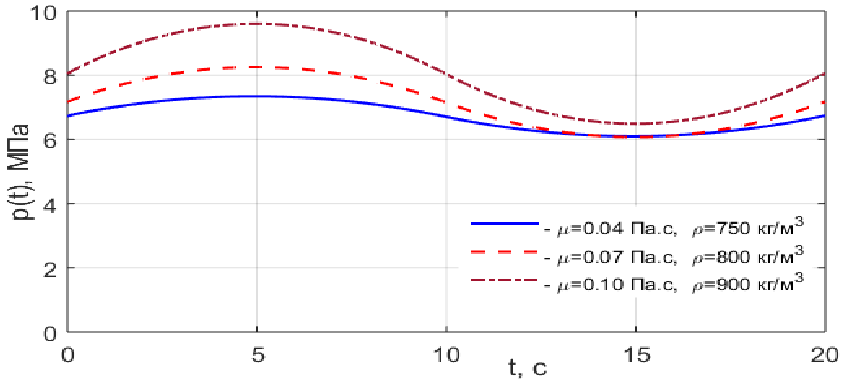

Figure 1 Graphs of dependence on the time of complete pressure on the plunger at different values of viscosity and oil density

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