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DEVELOPMENT OF LABORATORY SET–UP FOR STUDYING THE FLOW OF FLUID IN OIL PIPELINE

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This work describes the development of a training set-up designed as a part of oil pipeline for studying the liquid transportation. A 3D model of the pipeline was simulated, and mathematical calculations of geometrical and physical parameters were provided. The experimental oil pipeline was modelled on the base of simulated parameters and calculations, as well as methodological instructions for laboratory work were elaborated.

Key words:
Oil pipeline modeling, liquid transport, oil pumping

Introduction

Modeling of the oil pipeline, the system of pipes, intended for oil and gas pumping, should help solve the following problems. It demonstrates the oil pipeline operation in a lab environment. For another thing, the analytical model provides planning of any pipeline with reasonable accuracy and calculating its basic parameters as well. Moreover, mastering skills at analytical calculations is one of basic skills for graduates with qualification in «Workflow and production automation».

Theoretical background and calculations

Our experimental model consists of two interconnected reservoirs, two pumps, for liquid pumping, and a connecting pipe. Water was used as pumped fluid. All calculations were performed considering water transportation under normal operational conditions. All the mathematical operations and plotting were accomplished using MathCAD. The Autodesk Inventor was used for simulating and drawing this pipeline.

The relevant range of velocity for PVC pipes was predefined as [0.5; 3]. Consider four velocity values (1; 1,5; 2; 2,5) and calculate the corresponding diameters according by following formula

$$d = \sqrt{\frac{4Q}{\pi W}}$$

where Q is water flow rate, W is average water flow velocity, F is cross section area of a pipe, and d is the pipe diameter. The calculated value of corresponding diameters were presented in Table 1.

Table 1. Calculated values of diameters for different water flow rate

Average water flow velocity, m/s	$W_1 = 1$	$W_2 = 1{,}5$	$W_3 = 2$	$W_4 = 2{,}5$
Water flow rate, m^3/s	$Q_1 = 9x10^{-3}$	$Q_2 = 13x10^{-3}$	$Q_3 = 379x10^{-3}$	$Q_4 = 379x10^{-3}$
Pipe diameter, m	$d_1 = 0{,}107$	$d_2 =0{,}105$	$d_3 = 0{,}491$	$d_4 = 0{,}439$

The Q_i values were taken from the table of water usage depending on a pipe diameter. Then, we determined the optimal size of diameter, coming from geometrical considerations of construction and the least losses of pressure (we chose two results). According to the calculated value of d we chose the closest diameter of a standard pipe (it was d = 0.11 m) in a reference book. Then, by reverse calculation we calculated actual speed of water in a standard pipe with chosen diameter (W=1.789 m/s). Thus, we get the following water flow velocity:

$$W = \frac{4Q}{\pi d^2}\text{, W = 1,789}$$

To determine the flow mode in first pipeline section we calculated the Reynolds number

$$R = \frac{Wd}{v}$$

Where W is the average flow velocity; d is the pipe diameter; v is dynamic viscosity of water (at 20^0C)

$$R_e = W\frac{d}{v} = 1{,}96 \times 10^5$$

The value of the Reynolds number obtained is R_{e1}>R_{ecr}=2320, so the flow mode is defined as turbulent. In turbulent flow mode the thickness of laminar sublayer should be calculated as

$$\delta = 34.2\frac{d}{R^{0.875}} = 8.805 \times 10^{-5}$$

The friction coefficient λ is determined by Nikuradze formula when K_e = 0,005:

$$\lambda = \frac{1}{\left(1{,}74 + 2\log\left(\frac{d}{K_e}\right)\right)} = 0{,}05$$

The resistance coefficient of the PVC pipe was obtained from the table of coefficients. General friction losses in the pipeline were calculated as

$$h_{norm(1-2)} = b_1 * Q^2 = 2{,}89 \times 10^{-6}$$

where b_1 = 0,01 is the resistance coefficient for pipes of the diameter less than 200 mm.

Two cross – sections were chosen: 1-1 (at the 1^{st} reservoir output) and 2-2 (at the 2^{nd} reservoir input). The output pressure was calculated by Bernoulli equation

$$Z_1 + \frac{P_1}{\gamma} + \frac{W_1^2}{2g} = Z_2 + \frac{P_2}{\gamma} + \frac{W_2^2}{2g} + h_{norm(1-2)}$$

where Z_1, Z_2 are heights of the cross–sections, P_1 and P_2 are cross–section pressures, γ is water density of 999,97 kg/m^3, g is gravity acceleration, W_1, W_2 are the average flow velocities in corresponding cross–sections, $h_{\mathrm{norm(1\text{-}2)}}$ are pressure losses, P_1/γ, P_2/γ is the piezometric head, $(W_1)^2/2g$, $(W_2)^2/2g$ is the dynamic head.

Table 2. Data for the Bernoulli equation

Z_1, m	Z_2, m	W_1, m/s	W_2, m/s	$h_{\mathrm{norm(1\text{-}2)}}$, m	P_1, Pa	P_2, Pa
0	0.5	1.789	1.79	$2.89*10^{-6}$	101737.75	?

It provided the calculation of the pump power range necessary for normal work of the pipeline.

The equation of vertical lift performance is written as $H = a + (c + b)Q^2$, where

$$a = (z_2 - z_1) + \frac{(P_2 - P_1)}{\gamma},\ a = -2{,}89 * 10^{-6}$$

b_1 = 0,01 is the resistance coefficient for pipes of the diameter less than 200 mm.

$$c = \frac{8\left(\frac{1}{d^4}\right) - 8\left(\frac{1}{d^4}\right)}{g \cdot \pi^2}.$$

As the diameter is the same through the full length → c = 0.

The equation of vertical lift performance for this pipeline takes the form as follows:

$$H(Q) = 2{,}89 \times 10^{-6} + 0{,}01Q^2$$

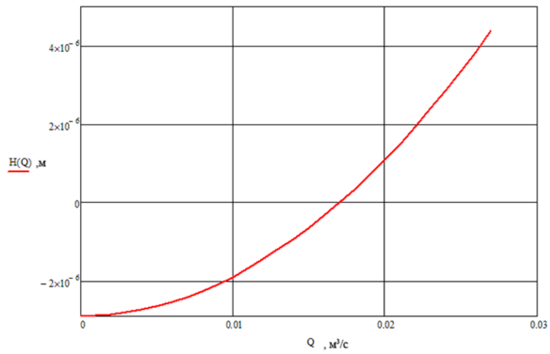

Fig.1. The H–Q Diagram

These values obtained can be considered as reasonable with regard to the geometry of the structure.

Then, external heat losses should be calculated. The flow mode was defined above as the turbulent one, so the necessary tabular values for the turbulent mode such as water heat emission and the Prandtl number were taken from reference books.

Then, the Nusselt number was defined, which characterizes the heat transfer rate between liquid and solid:

$$Nu = 0{,}021 R_e^{\;0{,}8} \cdot \Pr_g^{\;0{,}43} \left(\frac{\Pr_g}{\Pr_g} \right)^{0{,}25} = 831{,}63$$

The coefficient of heat transfer between water and pipe wall was calculated as

$$\alpha_1 = \frac{Nu \cdot \lambda_g}{d} = 4.634 \times 10^3$$

where λ_g = 6.96x10^{-4} W/m·deg (reference value) is thermal conductivity of water, d is internal pipe size.

Calculate the coefficient of heat transfer at free convection α_2 and the external heat losses Q_0.

$$\alpha_2 = 1{,}17 * \Delta t^{0{,}25} = 1{,}54$$

$$Q_0 = \frac{L \Delta t}{\dfrac{1}{\pi d \alpha_1} + \dfrac{1}{\pi d_2 \alpha_2} + \dfrac{\log(d_2/d)}{2.73 \lambda_1}},$$

where L is the pipeline length of 1,2 m, λ_1=6.96×10^{-4} W/m^2×deg is thermal conductivity of PVC. Q_0, heat losses, is 0,179 W.

This suggests that losses turned out small, so that additional insulation is not required.

Computer model and draft

To avoid the pipeline resonance with the surface, two rubber stripes were placed under reservoirs (rubber is one of the most effective damping materials).

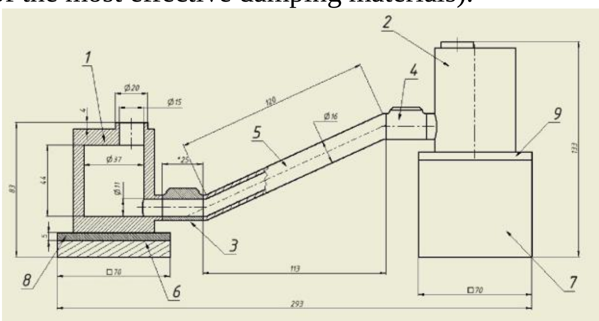

Fig.2. Model draft

1 - First reservoir; 2 — Second reservoir; 3 - Pump of the first reservoir; 4 - Pump of the second reservoir; 5 – Pipe; 6, 7 - Lower bases of reservoirs; 8, 9 – Rubber stripes under reservoirs.

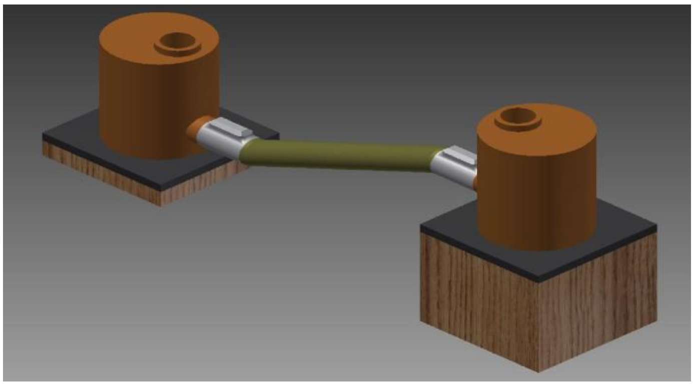

Fig.3. Graphic presentation of model (general view)

When developing the oil pipeline main characteristics – head losses and heat exchange should be calculated with high accuracy. The designed training set-up modelled as a part of an oil pipeline is considered to be used to prove the accuracy of these characteristics in lab environment. The pipe diameter (0,11 m), and the liquid flow velocity (1,789 m/s) were calculated as well as the head losses ($2,89\times10^{-6}$). Considering the minor heat exchange with environment (0179 W), it was decided that supplementary insulation and pump warm– up are not needed. Moreover, the designed set–up will be used in modelling the fault detection in oil pipelines.

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