Stationary Sampler for Mixed Probe Sampling from Mobile Tank

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Abstract Oil pipeline section repair requires its emptying from any products. It is possible to pump out oil using different methods. After truck with vacuum pump is used it is needed to take sample from truck tank. We suggest using of stationary sampler in order to simplify operation and to reduce operational time and negative effects of oil vapors on maintenance personnel and in order to get mixed sample. Previous works about liquid flow with continuous change of flow value along the distance were studied. Storage tank sampler with perforated tube and valve was taken as prototype. We represented sampler with five orifices, all of them on same vertical axis. In paper equations system for sampler design calculations are shown with device set up scheme. Technical-economical calculation result shown in this paper. This device is possible to use in others fields of oil industry after modernization.

1. Introduction
In the process of oil pipeline repair it is often needed to empty its section from products. This sophisticated technological operation requires large number of equipment and personnel. Technology of oil pipeline emptying depends from pipeline disposition. Here are possible solutions:
- in storage tanks of oil pumping stations;
- in parallel oil pipeline;
- in temporarily tanks or tank cars.

Depending of used scheme and equipment there are such methods of pipelines emptying as spontaneity flow, pumping equipment, mobile pump units [1], displacement by inert gas mixture or by combing methods above together.

1.1. Relevance and scientific importance of the subject
Oil can be pumped to tank car by mobile pump. Tank cars usually are equipped with vacuum pump. Sample is taken before oil will be put in underground storage tank. In accordance with GOST 2517-2012 probe is taken by mobile metal sampler from level equal to 0.33d of tank car from tank bottom. This means that only local sample from one level is taken. In order to increase quality and accuracy of sample it is needed to take mixed sample. We considered possibility of designing of a sampler which would be able to take probes from different levels of tank. In designing of such sampler it is needed to
determine orifices diameters and their vertical position in order to establish equal liquid flow through all orifices.

Storage tank sampler with perforated tube and valve was taken as prototype. We suggest sampler with five orifices, all of them on one vertical axis. Design of device is shown on Fig. 1. Orifice from first side of perforated tube is closed, from second side there is a valve. Oil goes from device to a tank with atmospheric pressure. Sampler position in tank car is shown on Fig. 2.

![Figure 1. Sampler design.](image)

We assumed in calculations that distance between orifices is more than length of their influence. That allowed us to use discrete type of flow change along the distance. So energy loss on each pipe section was calculated separately. Not relatively high amount of orifices in sampler also allowed us to use discrete calculations, so calculations volume wasn’t large.

We studied liquid movement in case of continuous flow change through the distance. In studies of V.M. Vakkeev and I.I. Konovalov [2, 3] this movement was described by dynamic equilibrium of object of variable mass, but discreteness of variable mass was not considered.

In works of G.A. Petrov [4, 5] movement of liquid with variable mass was studied in accordance with equations of dynamic equilibrium of variable mass point, impulse and Bernoulli equation for flow of constant mass.

In works of D.M. Mincin [6] movement of variable mass in pipes in accordance with law of conservation of energy was studied.

In works of V.B. Dulnev and V.A. Arhangelskiy [7, 8] equations of liquid movement with continuous flow change along the distance were obtained with help of theorem of impulse, equations were established in differential form.

N.I. Matushkin [9] received equation of pressure loss in case of non-constant density of liquid. His solution was based on Darcy-Weisbach equation along with additional empirical coefficient.

As result of research two methods for sampler calculation were chosen. After calculations were done results were compared. First method was based on A.D. Girgidov work [10]. Because of vertical position of sampler tube it was needed to consider gravity force of liquid also, so additional parameter was used in equation. Second method was used without any changes. Second method was described in Sirazetdinov F.M. work [11] («Designing of samplers with perforated tube for oil and oil products sampling from storage tanks»).
1.2. Formulation of the problem, theory

Section of the sampler with one orifice was point out as control volume by two cross-sections (Fig. 3). For this section equation of mass balance, impulse balance and mechanical energy balance were established.

Figure 2. Positional scheme of sampler in tank car.

Figure 3. Calculation element design.

1. Mass balance

\[ V_i \cdot S_i + q_i = V_{i+1} \cdot S_{i+1}, \]

\( V_i \) – liquid average velocity in \( i \)-th cross-section of pipeline;

\( S_i \) – square of \( i \)-th cross-section of pipeline;
\( q_i \) – volume flow of liquid in sampler through i-th orifice. From (1) we get

\[
V_{i+1} = V_i \cdot \frac{S_i}{S_{i+1}} + \frac{q_i}{S_{i+1}} = b_i \cdot V_i + \frac{q_i}{S_{i+1}},
\]

where \( b_i = \frac{s_i}{S_{i+1}} \). Because pipeline of constant cross-section square is used as sampler then \( b=1, \) i.e.

\[
V_{i+1} = V_i + \frac{q_i}{S_{i+1}},
\]

We get equation system, which represented below, in respect to that sampler diameter is constant through all its length

\[
\begin{align*}
Q_1 &= V_1 \cdot S_T \\
q_1 + V_1 \cdot S_T &= V_2 \cdot S_T \\
q_2 + V_2 \cdot S_T &= V_3 \cdot S_T \\
q_3 + V_3 \cdot S_T &= V_4 \cdot S_T \\
q_4 + V_4 \cdot S_T &= V_5 \cdot S_T \\
q_1 + q_2 + q_3 + q_4 + q_5 &= Q \\
q_1 = q_2 = q_3 = q_4 = q_5 &= \frac{Q}{5}
\end{align*}
\]

where \( S_T \) – square of pipeline cross-section.

2. Impulse balance projection on sampler axis:

\[
-a_i^0 \rho V_i^2 S_i + a_{i+1}^0 \rho V_{i+1}^2 S_{i+1} = P_i S_i - P_{i+1} S_{i+1} + \rho g S (Z_i - Z_{i+1}) - \tau_i \pi D_i L_i,
\]

as \( S_i = S_{i+1} = S_T \), so

\[
-a_i^0 \rho V_i^2 S_T + a_{i+1}^0 \rho V_{i+1}^2 S_T = P_i S_T - P_{i+1} S_T + \rho g S (Z_i - Z_{i+1}) - \tau_i \pi D_i L_i,
\]

where \( P_i \) – hydrodynamic pressure in i-th cross-section;

\( \tau_i \) – average tangent tension on sampler walls;

\( D_i \) – average diameter of i-th sampler section;

\( a_i^0 \) – momentum corrective;

\( \rho \) – density of liquid;

\( L_i \) – length of control volume.

We assume that flow movement and hydrodynamic regime is established and without abrupt changes, so \( a_i^0 \rho \rho g S = 1 \), normal tension in cross-sections of flow is equal to hydrodynamic pressure and pressure loss through length in control volume can be calculated using Darcy-Weisbach equation with velocity \( V_i \). Tangent tension \( \tau_i \) is determined from steady movement equation

\[
\tau_i = \frac{\rho g}{4} \frac{h_{li}^2}{L_i}
\]

\[
= \frac{\rho h_{li}^2}{4} \frac{V_i^2}{L_i}.
\]

where \( a_i \) – coefficient of hydraulic friction.

3. Mechanical energy balance

4. \( \rho V_i S_i h_{i} + \rho g Q_i h_{li} =

\rho g V_{i+1} S_{i+1} h_{e(i+1)} + \rho g V_i S_i h_{li} + \rho g Q_i h_{pp}i. \)
where $H_{el} = z_i + \frac{p_i}{\rho g} + \alpha_i \frac{V_i^2}{2g}$ – overall hydrodynamic pressure in $i$-th cross-section;

$z_i$ – distance from tank bottom to gravity center of orifice;

$H_t$ – orifice depth of immersion;

$h_{ppi}$ – a loss of pressure on way from orifice to section jet expansion.

We assume that jet in section expands on such value that liquid velocity in jet will drop from initial value $V_{ol} = \frac{Q_i}{\varepsilon_i S_{ol}}$ initial value, where $\varepsilon_i$ – coefficient of jet compression ($\varepsilon = 0.64$ for thin wall), to $V_{i+1}$ value. According to Borda equation

$$h_{ppi} = \frac{(V_{oi} - V_{i+1})^2}{2g}.$$ 

Orifices diameters in sampler were determined as a result of system of equations solution with condition of equable liquid flows obtaining from all levels. Calculations results are represented in table 2.

| №   | 1   | 2   | 3   | 4   | 5   |
|-----|-----|-----|-----|-----|-----|
| $d$, mm | 25  | 15  | 12  | 12  | 11  |

2. Summary

In order to check obtained calculation results Sirazetdinov F.M. method were used [1]. Comparison analysis of two methods results shows that difference is less than 3%.

Technical-economic calculation shows that pay off time of this device after installation is lesser then a year. This device using will simplify sampling process from tank cars. Also application of this device decreases negative effects of oil vapors on maintenance personnel.

3. References

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