CHARGE ACCUMULATION IN THE PROCESS OF FILLING OF ELECTRIFIED LIQUID INSIDE A RESERVOIR

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ABSTRACT. This study observes the problem with charge accumulation in the process of filling of electrified liquid inside a reservoir, to which Ohm's law applies.

Keywords: static electricity, electrification

НАТРУПВАНЕ НА ЗАРЯДИ В ПРОЦЕСА НА ЗАПЪЛВАНЕ НА НАЕЛЕКТРИЗИРАЩА СЕ ТЕЧНОСТ В РЕЗЕРВОАР

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РЕЗЮМЕ. Разглежда се проблемът за натрупване на заряди в процеса на запълване на резервоар с наелектризиращи се течности, за които е справедлива теорията на Ом за електризацията.

Ключови думи: статично електричество, електризация

Introduction

In the process of pumping of oil products along pipelines through pumps and filters, electrical charges are generated within the liquid. The filling of reservoirs is accompanied by the accumulation of electrical charges within the tanks' volumes. An electrical field with high voltage is generated in the gas space of the tank. The voltage of the electrical field is often sufficiently high to cause electrical discharges.

The risk of static electricity in oil industry, along with its effect on technical progress in the field of transport and storage of oil and oil products calls for the development of methods for prevention. This article studies the problems associated with static electricity during oil basic operations in the sequence that is determined by the technological production: charge generation and electrical leak in the pipelines; calculation of the electrical field in the reservoirs; methods for preventing static electricity risk.

To determine the static electricity risk in reservoirs, the electrical field energy should be regarded concurrently with the change of the concentration of oil product vapours within the vapour volume of the reservoirs during the forcing of electrified oil products [1].

This report focuses on the issue of charge accumulation during the filling of a reservoir with electrified liquid for which Ohm's law applies.

Exposition

1. Non-sectional tank

The input equation for charging in time is of the following type [2, 3]

$$\frac{dQ}{dt} = \left(\frac{dQ}{dt}\right)_{in} + \left(\frac{dQ}{dt}\right)_{rel}, \qquad (1)$$

where: $\frac{dQ}{dt}$ is the variation of charge Q, $[C]$, in the tank per unit of time t, $[s]$; $\left(\frac{dQ}{dt}\right)_{in}$ is the variation of charge in the tank per unit of time corresponding to the input current I_{in}, $[A]$ transferred by the stream of the tank incoming liquid; $\left(\frac{dQ}{dt}\right)_{rel} = I_{rel}$ is the variation of charge per unit of time determined by the charge relaxation.

For any moment of time t, equation (1) is valid where the phenomenon of relaxation is described. Employing this equation, we can put down

$$\left(\frac{dQ}{dt}\right)_{rel} = -\frac{Q}{\tau}, \quad (2)$$

where τ is the time-constant of the liquid relaxation, $[s]$.

Using the new notation, equation (1) is changed into

$$\frac{dQ}{dt} = I_{in} - \frac{Q}{\tau}, \quad (3)$$

The solution to equation (3) is

$$Q(t) = Q_{est}.(1 - e^{-\frac{t}{\tau}}), \quad (4)$$

where $Q_{est} = I_{in}.\tau$

The charge density is $\rho_V(t)$ established by dividing equation (4) by the liquid volume

$$\rho_V(t) = \frac{\tau.\left(1 - e^{-\frac{t}{\tau}}\right)}{t}.\rho_{in.V}. \quad (5)$$

For $t >> \tau$ we have

$$\rho_V(t) = \rho_{in.V}.\frac{t}{\tau}. \quad (6)$$

2. Sectional tank

We discuss the common case of a partition of the tank into two sections by means of a barrier.

The liquid enters the first section and flows into the second section through an opening in the barrier. The liquid level in the two sections is equal.

The input equation for section one is of the type

$$\frac{dQ_1}{dt} = I_{in} - I_{rel.1} - I_{tr.1,2}, \quad (7)$$

where $\frac{dQ_1}{dt}$ is the charge variation per unit of time in the first section; $I_{rel.1}$ is the relaxation current in section one; $I_{tr.1,2}$ is the current transferred by the liquid and entering section two.

We write equation (7) using a new notation

$$\frac{dQ_1}{dt} = I_{in.} - \frac{Q}{\tau} - \frac{Q_1.(V_0 - V_1)}{V_1.t}, \quad (8)$$

where $V_0 - V_1$ is the total filling capacity of the first tank..

We introduce the notations $Q_1^* = \frac{Q_1}{I_{in.}.\tau}$ and $f = \frac{V_0 - V_1}{V_1}$ and obtain

$$\frac{dQ_1^*}{dt} + \left(\frac{1}{\tau} + \frac{f}{t}\right).Q_1^* - \frac{1}{\tau} = 0. \quad (9)$$

The solution to equation (9) is as follows:

$$Q_1^* = \frac{\int_0^t e^{-\frac{t}{\tau}}.e^{\frac{1}{f}}.dt}{\tau.e^{-\frac{t}{\tau}}.e^{\frac{1}{f}}}. \quad (10)$$

The graphical dependence of $Q_1^* = \frac{Q_1}{I_{in.}.\tau.} = f.\left(\frac{t}{\tau}\right)$ is such that Q_1^* increases proportionally to the rise of $f.\left(\frac{t}{\tau}\right)$. After a given value of $f.\left(\frac{t}{\tau}\right)$, this proportion is disturbed and a steeper rise of $f.\left(\frac{t}{\tau}\right)$ corresponds to a minor increase of Q_1^*. The graph runs almost parallel to the $\frac{t}{\tau}$ axis.

The charge Q_2^* in the second section of the tank is determined by way of the charge variation in this section.

$$\frac{dQ_2}{dt} = I_{tr.1,2} - I_{rel.1,2} = I_{tr1,2} - \frac{Q}{\tau}, \quad (11)$$

where $I_{rel.1,2}$ is the relaxation charge in the second section.

Upon dividing equation (11) into $I_{in.}.\tau$, we get

$$\frac{dQ_2^*}{dt} = \frac{I_{tr.1,2}^* - Q_2^*}{\tau}. \quad (12)$$

To solve equation (12) with respect to Q_2^*, we need to have the numerical dependence of $I_{tr.1,2}$, determined by equation (7).

3. Approximate equation for determining the volume of a relaxation vessel

The variation in the amount of charge Q in the oil product that is forced into an earthed relaxation vessel is described by the following equation:

$$-\frac{dQ}{dt}=\frac{Q}{\tau}-i\ , \qquad (13)$$

where i is the current determined by the motion of the charged dielectric liquid in the pipeline; $\tau=\frac{\varepsilon_r.\varepsilon_0}{\gamma}$ (where ε_0 is the absolute dielectric permeability of the void: $8{,}86.10^{-12}\ \frac{F}{m}$, ε_r is the relative dielectric permeability of the liquid, and γ is the electrical conductivity of the liquid, $[\Omega^{-1}.m^{-1}]$).

Bearing in mind that there is no charge in the relaxation vessel at the initial moment of forcing the liquid, i.e. at $t=0$ and with $Q=0$, we get the following equation:

$$Q=i.\tau.(1-e^{-\frac{t}{\tau}})\ , \qquad (14)$$

Since the stay period of the liquid in the relaxation vessel $t>>\tau$, for the established mode, equation (13) changes into:

$$Q\approx i.\tau\ , \qquad (15)$$

In this manner, the amount of charge that is contained in the whole volume of the pumped oil product to be found in the relaxation vessel is approximately equal to the current i multiplied by the time for the product relaxation τ. The velocity of the flow in such a vessel is low; therefore, the charge generated in the vessel can be disregarded.

If V is the volume of the relaxation vessel, the average volume density of the liquid charge ρ_V is determined by the equation:

$$\rho_V=\frac{Q}{V}=\frac{i.\tau}{V}\ , \qquad (16)$$

The value of the current induced by the flow of liquid that passes into the vessel at the forcing speed of $G\left[\frac{m^3}{s}\right]$ is

$$i_{res}=\rho_V.G=\frac{\tau.G}{V}.i\ , \qquad (17)$$

Deriving from expression (17), we can approximately determine the necessary volume of the relaxation vessel that provides the leak of a given amount of charge during continuous forcing of the oil product in the tank:

$$V=\frac{\tau.G}{k_0}.100,\ \left[m^3\right], \qquad (18)$$

where $k_0=\frac{i_{res}}{i}.100$ is the amount of residual charge in the flow of the oil product from its initial value, $[\%]$.

It is worth noting that in formulating equation (18), the charge leak in the relaxation vessel is presumably due to the conductivity of the oil product and the convectional and diffusion current in the vessel itself which can both affect the charge leak in the vessel are not taken into consideration. Consequently, the actual necessary volume of the relaxation vessel might differ slightly from the calculated one. This is particularly valid for the dielectric liquid with specific volume resistance within the range of $10^{12}\ [\Omega.m]$ and higher.

Conclusion

A relaxation vessel should be used for removing hazardous accumulation of electrostatic charges during the forcing into tanks of combustible dielectric liquids with specific volume electrical conductivity of $10^{-9}\div10^{-13}\ [\Omega^{-1}.m^{-1}]$. It necessarily has to be employed in cases when, with the aid of pumps and filters that are themselves sources of mass generation of electrical charges, the liquid is loaded into tanks with gas and vapour spaces by means of short pipelines or by means of a pipeline filled with an insulation material (e.g. polyvinylchloride).

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The article is reviewed by Prof. Dr. K. Trichkov and Assoc. Prof. Dr. Romeo Alexandrov.