CHEMICAL ENGINEERING TRANSACTIONS
VOL. 59, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Zhuo Yang, Junjie Ba, Jing Pan

ISBN 978-88-95608- 49-5; **ISSN** 2283-9216
DOI: 10.3303/CET1759172

The Studies on the Static Electrification Distribution Regularities owing to Oil Product Flow in Oil Duct---a Review

Xiaogang Zhao*, Yang Peng, Yi Zhou, Zhan Guo

Dept. of Petroleum Supply Engineering, LEU, Chongqing 401311, China
Zxghg1991@163.com

The importance and historical research of the static electrification problem owing to oil flow in pipeline is overviewed. From three aspects of theory, experiment and simulation, this paper introduces the research methods and achievements in oil flow electrostatic field. Finally, on the basis of analyzing the existing problems, this paper also looks forward to the future research direction and trend in the field of static electrification problem owing to pipeline transportation of oil product.

1. Introduction

Oil is the lifeblood of the national economy, and in the process of storage and transportation of petroleum products, the pipeline is an important means of transport. One of the key factors affecting the storage and transportation security of petroleum products is the static electricity produced by the pipeline oil. In 2007, an explosion and fire accident occurred in a chemical depot located in Kansas, resulting in serious economic losses. After that people find that it is the oil flowing through the pipeline and pump that causes static electricity, and the oil and gas explosion is caused by electrostatic discharge. In the oil industry, according to statistics in China and Japan, more than 10% of the oil depot fire and explosion accidents are electrostatic accidents. The solutions to the electrostatic hazard still remain in the empirical grounding and setting safety velocity etc., the study of the distribution law of oil streaming electrification, which can provide theoretical and experimental support for electrostatic prevention and control measures scientifically, is still not enough. How to better solve the problem of electrostatic safety in the process of product oil transportation has gradually become the focus of attention.

2. Research status

The basic theory of the pipeline oil electrostatic distribution is the oil flow electrification theory. Related research started as early as 1913 when Dolezalek found static charge occurred with the fluid flow in the study of the flow characteristics of benzene and ether in the metal tube, then in the petroleum industry people also observed the phenomenon of oil flow electrification. In recent years, due to the deepening understanding of the oil flow electrification problem, more and more kinds of researches have been done in the field of electrostatic in China and abroad.

2.1 Oil streaming electrification correlation theory

The research on the theory of electrostatic current in started early, and its research is more active in three countries, which are the United States, Japan and France.
(1) Gavis & Koszman model (Gavis and Koszman, 1961)
Gavis and Koszman derive formulas for the calculation of low conductivity fluid flow in turbulent conditions:

$$I_s(x) = 2\pi r U_m \lambda^2 \frac{ZF}{\delta_d n^+}(C_{-o} - C_{-s})\left[1 - \exp\left(-\frac{x}{U_m \tau}\right)\right] \tag{1}$$

Please cite this article as: Xiaogang Zhao, Yang Peng, Yi Zhou, Zhan Guo, 2017, The studied on the static electrification distribution regularities owing to oil product flow in oil duct--- a review, Chemical Engineering Transactions, 59, 1027-1032 DOI:10.3303/CET1759172

Where r is the pipe diameter, U_m is the average velocity, λ is Debye length, Z is the ionic valences, F is Faraday constant, δ_d is the thickness of the diffusion layer, n^+ is the ion transfer number, C is the molar internal ion concentration in oil, C_{-s} is the interface ion molar concentration, τ is relaxation time.
(2) Touchard computing model (Touchard and Romat, 1981)
Touchard puts forward the calculation model of fluid electrification based on the physical and chemical corrosion mechanism at the solid-liquid interface.

$$j = K(q_{wd} - q_w) \tag{2}$$

Where K is the effective reaction rate constant, q_{wd} is the charge density under the condition of EDL's full development, q_w is the wall charge density.
(3) Tanaka computing model (Tanaka et al., 1985)
The influence of the external electric field on the electrification of the oil flow is fully taken into account by Takana, and the conclusion is obtained under the condition of external electric field and no external electric field. According to his conclusion, the distribution law of oil flow under the condition of no external electric field is:

$$q(x, r') = \frac{q_w}{\lambda}\exp(-r'/\lambda) \tag{3}$$

Where q_w is the surface charge density, λ is the Debye length, r' is the vertical distance to the wall, x is the distance to the duct inlet. At the same time, he believes that the charge separation of the solid and liquid interface goes into the fluid in the form of impulse current, the value of the current is only related to the concentration of ions in the fluid, flow regime and fluid velocity.

2.2 Research status of oil streaming electrification experiment

Electrostatic experiment of pipeline oil is an important way to verify the theoretical model and provide practical basis. The experimental method of oil flow static electricity can be divided into field measurement method and model analogy method. The field measurement method is a method of verifying the experimental data of the theoretical model through the measurement of the phenomenon of pipe flow in engineering practice. Whereas the field measurement method is gradually replaced by the analogy method because of the security problem. The model analogy method can be divided into pipe flow research method (Figure 1), rotating disk method (Figure 2), rotating cylinder method, conducting probe test method and so on from the experimental system (Okabe et al., 2002).

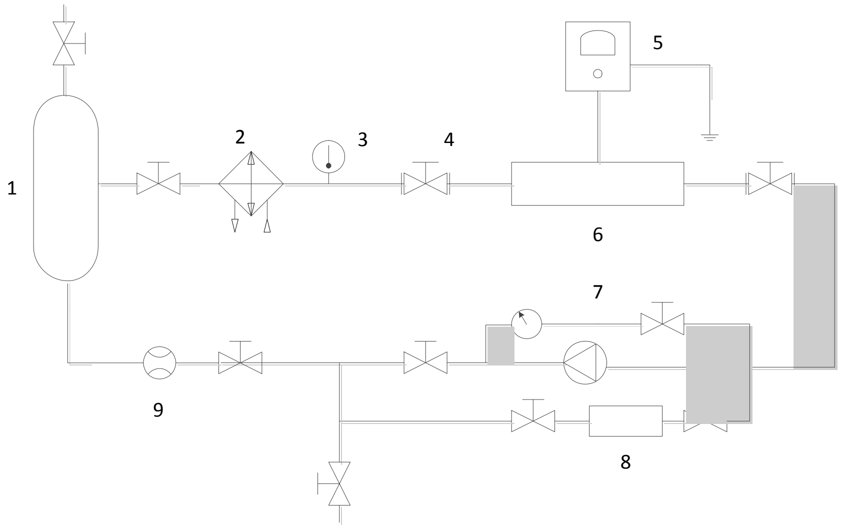

Figure 1: Pipe flow experimental system. 1: stainless-steel vessel; 2: heat exchanger; 3: temperature measuring instrument; 4: insulated flange; 5: pico-ampmeters; 6: charge accumulation duct; 7: pump; 8: conductivity measuring cell; 9: flow meters.

The experimental study on oil flow electrostatic began with product oil. The system can measure the parameters like temperature, flow rate and the conductivity of the fluid. The vessel can serve as a relaxation zone and can be used either for pressurization with gas or for oil recovering under vacuum. Pipe flow experimental method is one of the earliest ways to conduct practical research on streaming electrification. The system is usually made up with a loop inserted with different cells regarding the research tasks. To simulate the oil path inside transformer, the charge accumulation duct can be designed as a rectangular oil channel with electrodes inserted in PTFE frame. Many results come out by using the pipe flow experimental system. Huang and Liu (2013) study the streaming electrification of the electrostatic traditional mineral oil and an alcohol synthesis in comparison, the speed, the board state, the transformer oil aging condition and other parameters are discussed, it is found that under the same conditions the mineral oil produced more static electricity than alcohol synthesis, but with aging of the oil and device, the electrostatic charging of alcohol oil will be gradually reduced. Vaucelle et al., (2008) studys on the electrostatic problem of transformer oil flowing through the rectangular channel at different flow rates and temperatures, which is of guiding significance for practical production. EL-Adawy et al., (2009) from French studied on electric double layer oil flow electrification model with inadequate development of EDL based on the experiment, the determination of the space charge density is divided into static and dynamic space charge, at the same time it was found that the interfacial electrochemical corrosion is not only related with the chemical reaction but also the shear stress.

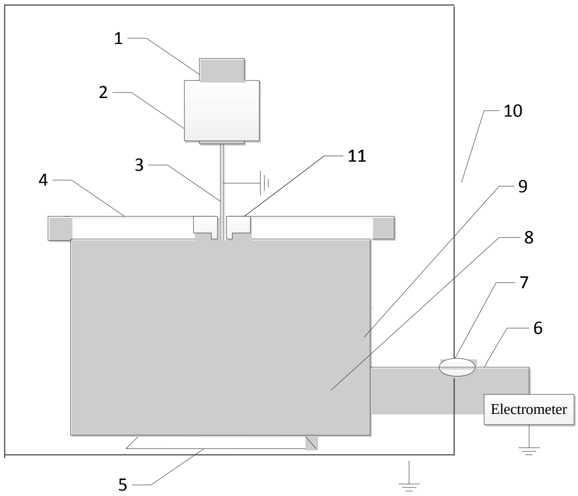

Figure 2: Spinning round disk system. 1: encoder; 2: DC motor; 3: rotating mandrel; 4: cover; 5: insulator; 6: coaxial cable; 7: insulator; 8: disk; 9: oil; 10: Faraday cage; 11: insulator.

Spinning round disk system was applied to doing related research from early 20th century. Through a vessel contained with experimental oil and a spinning disk (Figure 2), the system can measure the correlation between factors like velocity, temperature, oil quality and so on with the electrostatic current. Zmarzly et al., (2009) studied the problem of oil streaming electrification by rotating disc in a fluid container which show that the electrostatic charging depends on the parameter of the disc size and Reynolds number, the aging degree of transformer oil etc. Fofana et al., (2014) from Canada et al. used rotating disk method to study the influence of aging degree of transformer oil and insulation board on the streaming electrification, experiments show that with the increasing of temperature ,speed, the aging degree of disc coating material, and impurities in the oil, the generated charge is getting more. Talhi et al., (2016) in Canada found that with the increase of pressure, the cardboard porosity and roughness the electrostatic current increased by measuring the ECT of the flow in experiments under different pressure conditions, meantime, it is proved the number of free radical can affect the flow of oil static current by adding DDPH free radical reagent.

Washabaugh et al., (1994) made qualitative and quantitative analysis about the fluid charging phenomenon to a certain degree through the rotating and cylindrical electrode testing device. The device is similar to the spinning disk system in principle, which is composed of three parts, the inner tube of insulating material, the outer cylinder of metal and the filling insulating oil in the middle, the inner cylinder can adjust rotating speed while the temperature and humidity of the oil are controlled by the outer cylinder, the method is of certain innovation.

Conducting probe test method is based on the duct electrostatic sensor and work with the pipe flow method. As the probe inserted into the center of the oil duct can measure the space charge density, which is a key parameter in flow electrification, the experiment can be repeatable. Zmarly and Boczar (2009) did a lot of experiments for the pipeline streaming electrification phenomenon in case of laminar and turbulent flow in support of Poland Ministry of Science and Higher Education, using the spherical probe to measure axial charge density and streaming current different positions, the results show that with higher Reynolds number, the parabolic charge density distribution graphic of streaming current axial distribution is more gentle and balanced.

2.3 Research status of oil streaming electrification simulation

Oil streaming electrification simulation is of important significance for theory and practice, the simulation method is based on the mathematical model of the system, which can be converted into a simulation model prone to be programmed on the computer. Due to the high demands of the experimental device of electrostatic measurement, and vulnerable to the external interference conditions, the repeatability is low, while to carry out the related simulation work can not only greatly reduce the manpower, but also inspect the model accuracy fastly and effectively. The simulation of oil streaming electrification has become one of the hot topics in the field of oil flow. the present simulation method can be divided into several parts: simulation of the EDL, simulation of the oil duct and simulation of the charge distribution in oil duct.

Moreau et al., (1996) in the French power research center applied the three-dimensional computational fluid dynamics software estet to simulate the streaming electrification phenomenon in power transformer oil. In order to achieve this purpose, the estet is extended, which introduced the potential Poisson equation, the migration of fluid particles in the electric field, the recombination of ions in the chemical equilibrium and the electric field force in the N-S equation are introduced. The law of interfacial charge exchange is derived from the model of H. Walmsley, but it is related to the ion concentration on both sides of the interface. The transient and steady-state simulations which are in good agreement with the experimental data show that some of the experimental parameters leading to the huge potential gradient may be the cause of the hazardous discharge observed in power transformers. Kosei et al., (2007) proposed a new streaming electrification generating model based on the stress, simulated the oil duct and used the analysis method of DC field for computer simulation of transformer oil flow based on flow network algorithm, which was verified in experiment of different pipeline parameters. EL-Adamy et al., (2010) from France studied and simulated the development process of the electric double laye through the improved version of the finite volume method CFD tool Code_Staturne. The influence of speed, oil additives and impurities etc. on transformer oil streaming electrification, are studied, saving a lot of time and resources.

3. Protective measures for the flow electrification in oil duct

For the security of pipeline transportation when the static charge generated, we need to pay attention to prevention measures.

(1) Flow velocity control. As the flow electrostatic current is proportional to the flow velocity of the fluid, and the control of the flow velocity is the fundamental method to control the static electricity of the fluid. The initial velocity of the oil filling in oil industry is limited within 1 m/s. From the API standard in America, the flow velocity should be controlled between 4.5 and 6 m/s regardless of pipe radius. And Germany regulates that for any flammable liquid having a resistivity greater than 109 Ωm shall flow below 7.0m/s regardless of its diameter.

(2) The choice of pipe radius. When the flow rate is certain, choosing a proper pipe diameter is important, and there has been an equation for calculate the diameter and the flow velocity as $V^2D<0.64$.

(3) Temperature regulation. Temperature influences the development of fluid charge density and regulates temperature according to different conditions can adjust the distribution of fluid charge effectively.

(4) Enhance the electrostatic charge dissipation process. The generation and dissipation of electrostatic charge occur simultaneously so if the dissipative effect can be enhanced, the static electricity can be effectively eliminated. Pipeline with larger diameter can be used to increase the relaxation interval of the pipeline, which usually works like electrostatic buffer. An electrostatic buffer is essentially a region with a diameter of several times enlarged. It is usually installed at the end of the pipeline. The main function is to release the static electricity of the liquid. As shown in Figure 3, L is the length of the expansion section of the damper, d is the inner diameter of the pipeline for conveying oil, and D is the inner diameter of the buffer, in which D is about several times as many as d. Because D>d, the charged liquid enters the moderator flow is greatly reduced, thus the liquid has enough time to discharge to the ground, so the accumulation of electrostatic charge in oil duct is reduced. The moderator can only be adapted to the fluid with conductivity located between 10^{-9}S/m and 10^{-12}S/m. another important way is Electrostatic grounding. In the process of fluid filling the friction at tanks inlet/outlet, nozzles, flanges and other parts of the pipeline. If these components are made of suitable materials, less electrostatic generation will occurred.

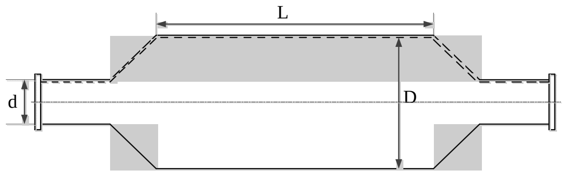

Figure 3: Structure of the electrostatic buffer

(4)Using electrostatic neutralizer. As a proactive measures to eliminate static electricity, the neutralizer process is finished mainly by electrons and ions to static electricity. The instrument ionizes air to produce positive and negative ions for neutralization in oil, finally achieving static balance (Figure 4). Compared with the electrostatic chemical additive method, this method will not affect the quality of the oil, and will not cause potential pollution to the outside environment. At the same time, it will be widely used in engineering because of its convenience in carrying. Steel tube shall be grounding so that the static charge can be released to the earth in time by the needle.

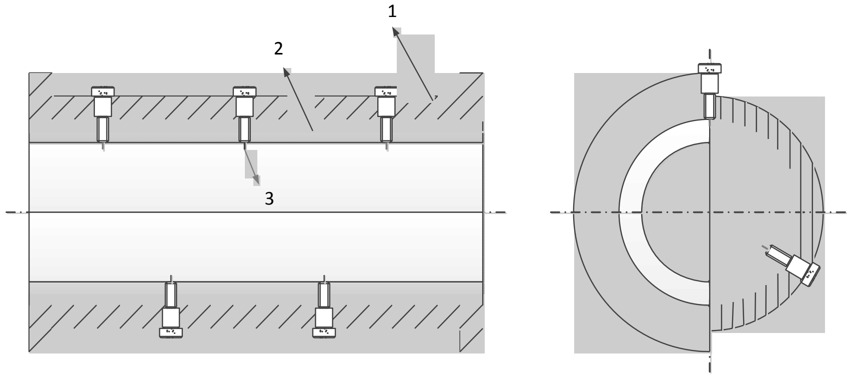

Figure 4 Structure of electrostatic neutralization device for oil pipeline. 1: steel pipe; 2: insulator; 3: discharge pin.

4. Conclusion

4.1 Main problems for the electrostatic distribution regulatities owing to oil product flow in pipeline

At present there are large space for the research of electrostatic distribution regulatities owing to oil product flow in pipeline, which is essential and meaningful for the ESD protection and dealing with the airport refueling flow electrification problems, combined with the review of the relevant literature, the oil streaming electrification problems existing in the study must be cleared and targeted before going into depth.

(1) Main problems for electrostatic theory and model in pipeline

Although the theoretical model of the streaming electrification owing to oil product flow in pipeline has been more accurate through continuous improvement, there are still some shortcomings. There are various theoretical models of streaming electrification in which the mechanism of oil flow electrification has not yet formed a unified and convincing understanding. And these models are often based on different mechanism, suitable for different conditions which is not specific and workable for the subject of electrostatic distribution regularities owing to oil product flow in pipeline.

(2)The main problems for electrostatic experiment in pipeline

A lot of experiments have been carried out on the subject of streaming electrification, but the research still has some limitations. The experimental achievements are mostly concentrated in the power industry, although the conclusion has certain guiding significance to the cause of streaming electrification in pipeline, but due to the different conditions of the applied electric field, the flow of media etc. the experiment do not fully meet the actual condition in the oil products transporting industry.

(3)The main problems for electrostatic simulation in pipeline

The current research on the electrostatic simulation in pipeline is not mature enough, and there are both much developing space and great potentialities. The simulation study has been carried out on the basis of different streaming electrification model and theory, and the analysis softwares are also different, so it is of no generality. And numerical simulation methods are used in high dependence on the accuracy of the theoretical formula which is often made more simplified, so only visual simulation results can't reflect the situation preciously.

4.2 Research destination of the Static Electrification distribution regularities owing to oil product flow in pipeline

At present, there are many problems and limitations in the streaming electrification field which are also driving force and targets. For instance, the theory is not solid enough, there are some deficiencies in the simulation methods, the experimental data under the condition of turbulent flow is lacking to support the research, and so on. On the basis of that, the following aspects are presented in the study of the electrostatic distribution law of oil pipeline. Making use of the basic formula fitted with the electrostatic micro mechanism and combined with the boundary conditions to derive and establish the mathematical model for the oil product streaming electrification, and to discuss the adaptability at transient large flow gradient; Using computer numerical simulation method to simulate the static current in the pipeline and makes analysis and research to search for the generation, accumulation and dissipation regularities; To measure the numerical value of the electrostatic accumulation and dissipation through the establishment of pipeline streaming electrification test bench, doing mechanism research and verification, studying the degree of correlation between the physical property and the electrostatic current through contrast test, obtaining the operating measures in the turbulent conditions owing to oil product flow in pipeline. In a word, the research on the electrostatic field of the pipeline oil is of great significance both in theory and in practice, it is necessary to study the basic distribution law of the oil and gas by mutiple research methods.

Reference

El-Adawy M., Cabaleiro J.M., Paillat T., Moreau O., Touchard G., 2009, Journal of Electrostatics, Elsevier, 67(2), 354-358.

El-Adawy M., Paillat T., Cabaleiro J.M., Touchard G., 2010, Industry Applications Society Meeting, IEEE, 18(5), 1-8.

Fofana I., Bouslimi Y., Hemmatjou H., Volat C., Tahiri K., 2014, International Journal of Electrical Power & Energy Systems, Elsevier, 54, 38-44.

Gavis J., Koszman I., 1961, Journal of Colloid Science, Elsevier, 16(4), 375-391.

Liu Q., Liu Z., Yang G., 2013, Electrical Insulation and Dielectric Phenomena, IEEE, 1026-1029.

Okabe S., Taniguchi Y., Mori S., 2002, Proceedings of the Transmission and Distribution Conference and Exhibition, Asia Pacific IEEE/PES, 1, 313-316 .

Talhi M., Fofana I., Flazi S., 2016, Journal of Electrostatics, Elsevier, 79, 25-32.

Tanaka T., Yamada N., Yasojima Y., 1985, Journal of Electrostatics, Elsevier, 17(3), 215-234.

Touchard G., Romat H., 1981, Journal of Electrostatics, Elsevier, 10(81), 275-281.

Tsuji K., Muto H., Kise K., 2007, Report - Conference on Electrical Insulation and Dielectric Phenomena, IEEE, 485-488.

Vaucelle R., Paillat T., Moreau O., Bertrand Y., Cabaleiro J.M., Touchard G., 2008, IEEE International Conference on Dielectric Liquids, IEEE, 1-4.

Washabaugh A. P., Zahn M., 1994, Conference Record of the 1994 IEEE International Symposium on Electrical Insulation, IEEE, 133-136.

Zmarzly D., Boczar T., 2009, Transactions on Dielectrics & Electrical Insulation, IEEE, 16(6), 1-4.