Flow Electrification in Highly Turbulent Flows
--Application to Liquefied Gas Manipulations--

G. Touchard
Electrofluidodynamic group, LEA, (UMR 6609 of CNRS), University of Poitiers, France

Abstract—Due to their very low viscosity, liquefied gas flows can reach very high velocity even in pipes of small diameters. In another hand they have generally a very weak electrical conductivity, even smaller than hydrocarbons liquids. This means that the electrical double layer thickness is rather big (several mm). But as the flow velocity is generally high, the Reynolds number can reach very high values. Thus this highly turbulent flow can convey a large part of the diffuse layer, the streaming current is important while the dissipation of charges is very low due to weak conductivity. This leads to the generation of very high potential which is a worrying problem for industry using or manipulating inflammable liquefied gas. In this paper we first analyze the phenomenon. Then, we relate two kinds of experiments. The first is made on a special experimental setup performed in the laboratory and used with liquid nitrogen. The second is a real size experiment made "in situ" during Liquefied Natural Gas (LNG) tanker unloading.

Keywords—Flow electrification, Electrostatic hazards, LNG

I. INTRODUCTION

It is now a well known fact that very high potentials can be generated by the flows of large quantities of dielectric liquids. This is specially the case for hydrocarbon liquids but also with liquefied gas [1-4]. For such liquids the flow is highly turbulent and partly a two phases flow. We have made flow electrification experiments in the laboratory for a long time, first on hydrocarbon liquids, then on liquefied gas. The liquefied gas transport manipulation and storage are especially worrying for two main reasons. First, this kind of liquid has very low electrical conductivity, even much lower than hydrocarbon liquids, thus the charge generated takes a very long time to dissipate. The second reason is that in many industrial cases these liquid are inflammable and have a very low Ignition Minimum Energy (IME). Two more reasons in case of Hydrogen liquid are its very low kinematic viscosity which induces high turbulent flows and its rather high space charge density in the double layer even if its electrical conductivity is much lower than all the other liquefied gas.

More, the solution used for hydrocarbon liquid which consists to dilute additives in order to reduce the electrical resistivity cannot be used for liquefied gas.

Finally, liquefied gas flows are often two phases flows which are supposed to generate more static electricity than a simple liquid flow.

For all these reasons it is important to study flow electrification for such liquid and to determine the influence of the ratio liquid/gas on the charge generation.

II. CHARGE TRANSPORTED BY A TURBULENT FLOW

For any kind of flow, the space charge density transported in a tube of circular cross section is given by the following integral:

\[ Q = \frac{1}{\pi R^2 U_m} \int_0^R \rho U r dr \]  (1)

In this expression \( R \) is the radius of the pipe, \( \rho \) the local space charge density, \( U \) the local axial mean velocity and \( U_m \) the flow rate velocity. To compute this integral for a turbulent flow, we must know the velocity profile and the space charge density profile. This can only be performed numerically [3] and has been done in the laboratory using two different approaches. One consider the perturbation of the diffuse layer by the radial fluctuant velocity, then two zones can be considered, one perturbed by the turbulence the other not. Finally the charge transported by the flow in these two zones is computed. The other approach consists to compute the charge in the diffuse layer taking into account a molecular diffusion reinforced by the eddy diffusivity of the turbulent flow, then the charge transported is computed. These two approaches give in fact similar results.

III. LABORATORY EXPERIMENTAL SETUP

It is shown in Fig. 1 and mainly composed of four cryostats. The first one (1) full of liquid nitrogen, is used as a storage vessel. The second vessel (2) has a double envelope in order to well maintain the temperature. It is used as a pressurization vessel, though a pressure is applied on this vessel in order to make the liquid flowing through the capillary tube (3) which is also a small cryostat. Thus, inside the capillary tube, as it is well
thermically insulated, when the liquid has been flowing enough to put the tube at the same temperature, the liquefied gas remains mainly in liquid phase. Nevertheless, at the beginning of the flow until the tube has reached the temperature of the liquid nitrogen, we can notice the influence of the percentage of gas on the flow electrification process. This is performed with a special fiber glass probe (5) inserted in the collecting vessel (4) in front of the outlet of the capillary tube. The collecting vessel is itself a cryostat which inner part is also electrically insulated in order to measure the current due to the flow electrification of the liquefied gas flowing through the capillary tube. The current is measured with a Keithley picoammeter. As this equipment has been used for other liquids like hydrogen liquid and liquefied natural gas, which are very inflammable liquids, everything can be pneumatically controlled from another location. The temperature of the liquid, the liquid level in the pressurization vessel, the gas pressure, the streaming current and the percentage of gas at the outlet of the capillary tube are recorded all along the experiment.

IV. TWO PHASES FLOW EXPERIMENTS

Experiments have been made with this equipment on liquid nitrogen with different ratio liquid/gas. To make this experiment the measures are performed at the beginning of the flow of the liquid nitrogen through the capillary tube. As this tube has at the beginning of the flow a higher temperature than the liquid nitrogen, a large part of the nitrogen evaporates, thus the ratio liquid/gas is rather low, then, as the temperature of the capillary (which is in a cryostat) reaches the temperature of the nitrogen the ratio liquid/gas is increasing. We can see in Fig. 2 the space charge density transported in a stainless steel tube of 2.5 mm of diameter and 1 m long. The different pressures give different flow rates. It seems that in this case the charge transported is slowly increasing with the ratio liquid/gas.
V. STATIC ELECTRICITY DURING LNG TANKER UNLOADING

These experiments were made in the methane terminal of Gaz de France (GDF) in Fos Sur mer. The reason of these experiments is an I.M.O. (International Maritime Organization) recommendation which stipulated that an insulating material part must be placed between the unloading pipes of the boat and the pipes of the pontoon during a LNG tanker unloading. The reason of such recommendation was probably due to some hypothetic sparks observed in a US port during the disconnection of a tanker and the officers of I.M.O. thought that this spark was due to a potential difference between the tanker and the pontoon as the tanker was freshly painted with an insulating painting.

In another hand, as the French Gas board Corporation (GDF) was more worrying about static charge generated on the insulating material itself than to
an hypothetic potential difference between the boat and the port which could be able to generate a spark. GDF did not want to apply such recommendation, but to be allowed to pass over the recommendation they had to prove its inconsistence, that the reason why GDF asked our laboratory to make these "in situ" experiment.

Thus, we have measured the electrical potential and the current generated during the different phases of the unloading of a methane tanker. General diagrams of the equipment are given Fig. 3, 4, 5 and 6. Photographs are shown in Fig. 7 to 10.

A. Potential difference between the boat and the Pontoon

The first part of our study was to measure the evolution of the potential difference between the tanker and the pontoon before and during the unloading. For that, just when it arrives in the port and before it was stowed to the pontoon, a wire was connected to the tanker and we measured the potential. Then this potential was observed all along the operation.

The potential difference is plotted in Fig. 11 during two set of experiments. As we can see the potential difference is always in the order of 0.150 V which does not explain the worries of I. M. O.

B. Electrical potential generated on the grid inside the pipe

A grid was placed inside the pipe and insulated from it, in order to observe the potential generated by the flow of L.N.G. during the unloading. Two different grids have been used Fig. 5 and 6, the second one had a better insulation but a smaller diameter than the first one.

The electrical potential on the second grid was measured with an electrostatic voltmeter. This potential is growing very fast at the beginning of the unloading (Fig. 12) which corresponds to the two phase flows, then tends to remain constant. This rather high potential shows that it is convenient to be very careful that no air remains in the pipe before the unloading in order to prevent any ignition.

C. Streaming current on the grid inside the pipe

The current has also been measured on the two grids during the unloading. The currents are roughly proportional to the velocity of the flows (Fig. 13). Thus, the space charge density transported seems to be nearly independent of the Reynolds number. This behavior seems to be consistent with the theoretical analysis [3].

VI. CONCLUSION

The space charge density transported by a highly turbulent flow, as it is very often the case for flows of cryogenic liquids, must be numerically computed.

The effect of the two phase flow is not yet very well understood and we need more experiments to point out its influence on the streaming current.

The experiments made during the unloading of a methane tanker show that the I.M.O. recommendation which stipulate to put a part made in insulating material at the junction between the tanker and the pontoon is not need.

In another hand, the high electrical potentials generated inside the pipe point out the necessity of a good sweep out of the air before the operation of unloading.
REFERENCES


