Journal of Electrostatics 71 (2013) 1041–1045

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Laboratory ignition of hydrogen and carbon disulphide in the atmospheric air by positive corona discharge☆

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ARTICLE INFO

Article history:
Received 28 March 2013
Received in revised form
22 July 2013
Accepted 13 September 2013
Available online 27 September 2013

Keywords:
Corona discharge
Ignition
Hydrogen
Carbon disulphide

ABSTRACT

Experimental attempts of ignition of sensitive explosive atmospheres by continuous positive corona discharges in coaxial electrode system were conducted in laboratory conditions. Sixty five explosions of hydrogen (H_2) and forty of carbon disulphide (CS_2) were forced. Both atmospheres were ignited by the minimum power 1–2 W, the minimum ignition current 100–130 μA at the ignition voltages 12–30 kV (for CS_2) and 16.5–25 kV (H_2). To prevent the energetic sparks, the high voltage resistor 1 MΩ was introduced in series with corona wire.

1. Introduction

Corona is an one-electrode, low energy discharge brought on by the ionization of the air around the energized conductor, if the field strength exceeds the breakdown value of the air locally, but not across the whole distance to the opposite electrode. The thin area around the conductor, up to a few hundred micrometres, is a region of charge carriers multiplication and plasma generation. In this space, called an ionization region, or plasma region, the reduced electric field E/N strength is greater than 120 Td (1 $Td = 10^{-21}$ V m^2), where N is the molecular density, in atmospheric air. At the field strength enough high, the corona streamer form of discharge can develop. In that form the pulses of plasma filaments can lengthen up if voltage increase, and finally can change to spark discharge. The length and the thickness of the streamer can achieve a few centimetre or more and a few hundred micrometres respectively. There are possible negative (from the thin cathode) and positive (from the thin anode) streamers. The positive streamers start to propagate at the essentially lower values of a voltage than the negative streamers, in the same electrode system. In research done by Briels et al. [1] for pin-to-plane distance equal to 40 mm only the positive streamers propagated in the potential range 5–40 kV and negative started above 40 kV. The total energy dissipated in the gap by positive streamers was nearly twice of that for negative discharges. For those reasons the ignition by corona discharges, seems to be easier attainable by positive than by negative discharges. Positive corona from a thin wire surface is characterized by the plasma bursts and streamers leading finally to the sparks or to the glow if the current is limited. Ion temperature in the streamer is about 1000 K [2]. Out of the plasma region, called unipolar region, dominate positive ions as a current carriers, and their temperature is close to that of an ambient air.

There is a dose of uncertainty about the risk of ignition some sensitive explosive atmospheres by positive corona. Some researchers claim that corona, as a discharge of diffusive nature, cannot be incendive (e.g. Refs. [3,4]). In common opinion of many experts corona can ignite some sensitive atmospheres like a vapour of carbon disulphide/air mixture [5,6]. In 2000, T. Pratt claimed that "Conventional wisdom has it that an optimum hydrogen/air mixture can be ignited by corona discharge, but there are no definitive references to the experimental work" ([6], p. 59). Since then many research works have been done to explain if the corona discharge from the metallic object previously charged by electrified dust particles (e.g. iron oxides) could ignite the hydrogen/air mixture (e.g. Refs. [7–11]). Some number of ignitions has been noticed, but it has not been clear which kind of discharge had caused them. In those reports, the polarisation of corona has not

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http://dx.doi.org/10.1016/j.elstat.2013.09.007

been discussed. The incendivity of the negative corona discharge in the vicinity of sensitive explosive atmospheres cannot be excluded at the moment, because the negative corona streamers can dissipate the energy of order of few millijoules in the gap [12]. Unfortunately this is difficult to find in the literature of the subject any reports confirming ignition of explosive atmospheres by the negative corona streamers. On the other hand, in case of more energetic one electrode discharges like brush discharges, the positive discharges are much more incendive than the negative [13].

The question is if the plasma region is large enough to heat the atmosphere to the temperature higher than its auto-ignition temperature (AIT). AIT of the hydrogen is uncertain and ranges according to different sources from 500 to 600 °C, the most probable is about 520–560 °C. AIT of carbon disulphide is 100 °C [3]. Both AIT values are lower than the temperature of positive corona streamer.

This is not predictable theoretically, if the streamer of corona is enough large and its duration prolongs enough to cause an ignition. For that reason the author undertook the experimental study, to find some numerical values of the corona parameters like current, voltage and power, necessary to evaluation of the ignition risk for the most sensitive atmospheres.

Usually two laboratory models of the electrode systems are commonly used for generating corona discharge: thin wire placed coaxially inside conducting pipe or sharp tip placed over the metallic plate. The second model like sharp edges also, is closer to the realistic industrial conditions, but in this preliminary research the coaxial system was preferred, as the electric field space distribution and intensity are quite simple to calculate unlike point-to-plate geometry. For safety reason, the measurements had to be made in closed, explosion-proof chamber, which metallic shield would distort the electric field distribution around the pin electrode in an uncontrolled way.

2. Methods and materials

Two known flammable media of the lowest MIE (minimum ignition energy) values at atmospheric conditions, excluding explosives, are mixtures of the air with hydrogen (MIE = 0.016 mJ) or with carbon disulphide vapour (MIE = 0.009 mJ) [5]. Both atmospheres were tested in the presented experiments. The experimental set-up consisted from the explosion chamber (Figs. 1 and 2), HV DC supplier and set of two flow rate mass controllers equipped with output mixer for generating the hydrogen explosion atmosphere. The carbon disulphide was applied in a liquid form and it evaporated completely inside the chamber during 1–2 min.

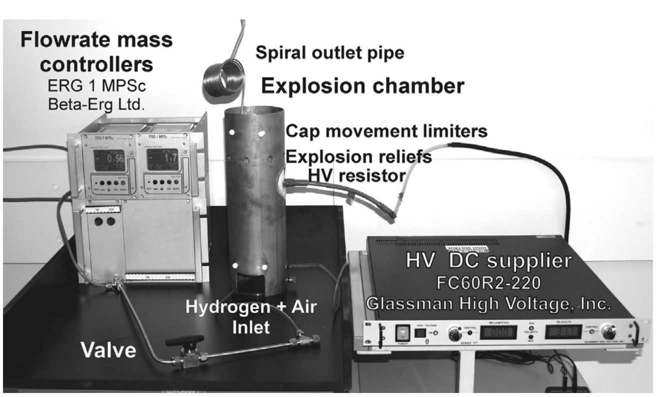

Fig. 1. Experimental set-up. On the left hand side – set of two flow rate mass controllers with output mixer, to generate the hydrogen atmosphere. In the centre – explosion chamber. On the right hand side – positive HV DC supplier.

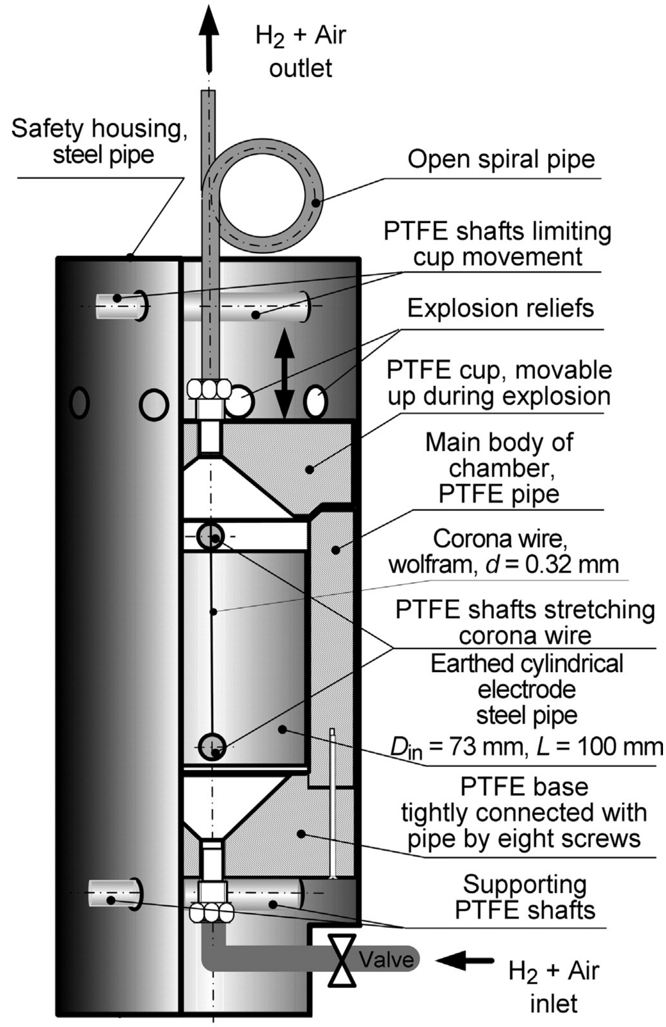

Fig. 2. Section view of explosion chamber.

The author used the explosion chamber, made from PTFE (Polytetrafluoroethylene), to avoid current leakage at high voltage. The main body of the chamber was a pipe with 130 mm length, 111 mm outer diameter and 75 mm inner diameter. The corona discharge electrode system was a coaxial type. Corona electrode was a wolfram wire with 0.32 mm diameter and 100 mm length, which was stretched on the PTFE shafts. The cylinder electrode was a steel pipe with inner diameter 73 mm and length 100 mm. The bottom of the chamber was tightly closed with the PTFE base, which was connected to the source of hydrogen atmosphere, through the valve. The base and the body of the chamber were connected with eight screws. The PTFE cap was put on the chamber and at the atmospheric pressure inside, their contact was leak proof. Just after ignition the cap was pushed upward by pressurized gas and released it through the safety holes. During the filling of the chamber with hydrogen atmosphere, the gas pressure inside of the chamber was close to that of ambient atmosphere, because the gas outlet in the cap was open. The spiral pipe was placed between the chamber and open space only, to avoid hydrogen running away after the valve was closed. The total inner volume of the closed chamber was 509 ml.

Two coupled flow rate mass controllers (ERG050 and ERG200, product of Beta-Erg, Ltd., Poland) took automatically programmed amount of hydrogen and dry, clean air, from the gas cylinders. The first controller was calibrated for hydrogen, and its maximum air