ON THE USE OF THE "ELECTRIC WIND" TO IMPROVE THE REMOVAL EFFICIENCY OF AIR POLLUTANTS TREATED BY CORONA DISCHARGES

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ABSTRACT. To test the capability of the "electric wind" to increase the efficiency of corona depollution processes, experiments have been carried out with traces of SO_2 as a pollutant in synthetic air, with a high-field electrode in the form of a small loop as a cathode and with a liquid electrode formed by distilled water as a pollutant collector. Results show that the method is promising.

INTRODUCTION

Reactors based on corona discharges stand among the plasma reactors which can be used to generate chemical reactions for depollution purposes. However, well exploited, one of their specific features should bring a substantial added value to the method. It lies on what is commonly called the "electric wind" [1] and which corresponds to an hydrodynamical gas flow induced by momentum and energy transfer from the ions, produced by the discharge, to the neutral gas, giving rise in point-to-plane electrode systems, to a gas jet directed along the gap axis from the high-field electrode (the point) to the low-field electrode (the plane).

As a matter of fact, we shall see how this flow, which is induced by the discharge with a very small energy consumption [1], can have a beneficial influence through different ways :

- as a means to supply the gas with water molecules for the production of radicals useful for the chemical destruction of the pollutants,

- as a tool to drain the pollutants dispersed in a vessel into the active region of the reactor,
- as a tool also to convey part of the pollutants, in their initial form or in a transformed form, as well as toxic by-products which may be formed by the discharge, towards a water cell used as a collector for the soluble pollutants or derivatives.

In order to help our appreciation on these effects, some unfavourable conditions from a depollution point of view have been chosen for our investigations, namely at first a large vessel (25 cm diameter) containing a big volume of gas (30 litres).

EXPERIMENTAL SET-UP AND CHARACTERIZATION OF THE CHEMICAL PRODUCTS INTERCEPTED IN THE WATER CELL

The electrode arrangement used for the study is composed on one side of a 1 mm diameter loop made of a 100 μm Pt wire and working as a cathodic high-field electrode, and on the other side of the surface of a water sheet connected to earth by an immersed W wire through an amperemeter. This liquid anode consists of distilled water renewed for each experiment and serves both for the recuperation of part of the polluting products coming from the discharge gap and for their analysis. The corona gap length was fixed at 15 mm for all measurements reported in this paper. Experiments were performed inside a large vessel as mentioned above and in flowing gas with humid synthetic air, pure or with some traces of SO_2 (concentrations ≤ 5 ppmv). Some details on the gas conditioning system are provided in the scheme of the Fig. 1.

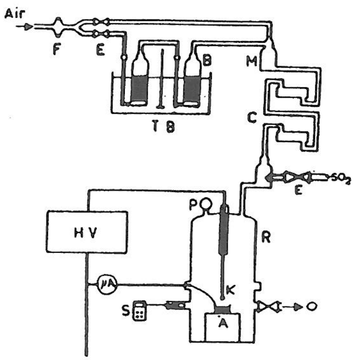

Figure 1. Block diagram of the corona discharge set-up. F : sintered-glass filter, E : electrical valves, B : bubblers, TB : temperature-controlled bath, M : mixing cell, C : condenser, P : pressure regulator, HV : high voltage power supply, μA : amperemeter, R : reactor, K : high-field electrode, A : water-filled collector (anode), S : humidity and temperature sensors, O : effluents outlet.

Chemical species intercepted from the discharge gap and dissolved in the water cell were identified by high pressure liquid chromatography (HPLC Dionex) to be essentially SO_4^{2-} and HSO_3^- anions, originating from the SO_2 pollutant and NO_2^- and NO_3^- anions representing air by-products formed by the discharge, while the corresponding concentrations in H_3O^+ cations were determined by pH-metry measurements.

RESULTS

1. On the action of the electric wind as a purveyor of water molecules to the discharge gap and on the rôle of these molecules for the oxidizing power of the discharge.

Submitting humid synthetic air with SO_2 traces to the discharge leads to a rather complex network of possible reactional paths but on the Fig. 2 which shows the most probable of these paths, one can see that most of them are monitored by $OH^{\bullet}$ and $H^{\bullet}$ radicals coming from the dissociation of H_2O [2,3].

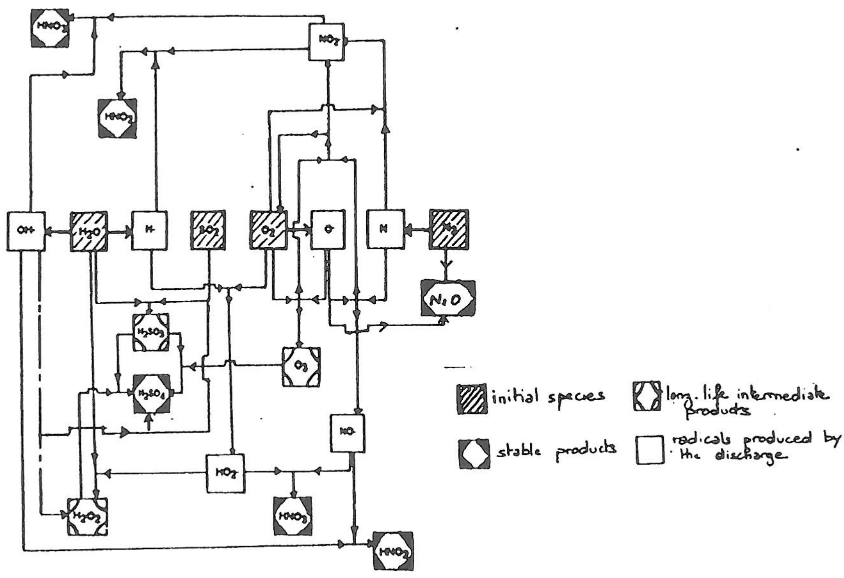

Figure 2. Chemical diagram of the reactional paths the most probable in a corona activated air + H_2O + SO_2 gas mixture.

Part of the energy exchanges between the electric wind and the water in the cell is spent in accelerating the evaporation of the water as it is illustrated by the curves of the Fig. 3. Moreover, these curves show that the electric wind acts, by this way, as a regulator which brings the water content of the gas, whatever its initial value, to an equilibrium state, probably close to the saturation, thus favouring the production, by the discharge, of $OH^{\bullet}$ and $H^{\bullet}$ radicals useful for the oxidation of H_2SO_3 in H_2SO_4.

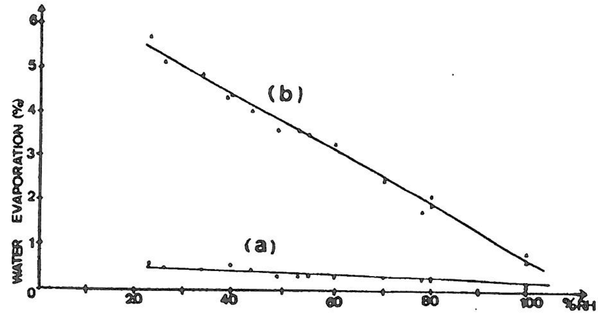

Figure 3. Water evaporation from the water collector as a function of the relative humidity of the gas in the corona vessel. $[SO_2] = 5$ ppmV, Q = 5 l/min. (a) : corona off. (b) : corona on at I = 20 μA. t = 30 min for each measurement.

2. Chemical species identified from the water cell.

The transformation of SO_2 into H_2SO_4 seen on the diagram of the Fig. 2 shows a chemical path for its destruction. But, as it was evoked above, the electric wind provides a supplementary electrodynamical way by its capability to drag the pollutant directly from the gas into the water cell where it will be transformed.

The chemical analysis of the aqueous solution after a gas treatment allows to measure the efficiency of each of the two processes separately, SO_2 oxidized in the gas phase leading in the water to

$$SO_2 + 2OH^{\bullet} \rightarrow H_2SO_4 \qquad (1)$$

and then to

$$H_2SO_4 + 2H_2O \rightarrow SO_4^{2-} + 2H_3O^+ \qquad (2)$$

while the SO_2 molecules which are intercepted in the water cell after having escaped chemical transformations in the gas are splitted into HSO_3^- and H_3O^+ ions according to the reaction :

$$SO_2 + 2H_2O \rightarrow HSO_3^- + H_3O^+ \qquad (3)$$

As it is visible on the Fig. 4, as well for the by-products of the discharge (NO_x) as for the pollutant to be treated (SO_2), an increase of the current and/or of the duration of the discharge leads to a linear increase of its oxidizing efficiency. However, persevering with the same way of thinking as for the vessel size, in order to optimize the demonstrative efficiency of our approach on the benefits which could be obtained from the electric wind for the efficiency of corona depollution processes, our investigations were carried on with low currents (20 μA), enabling to work on the electric wind contribution with a magnifying lens as shown by the results which will be presented in the next section.

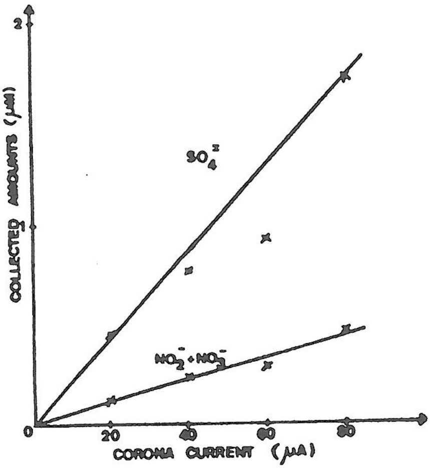

Figure 4. SO_2 oxidation and correlated NOx production, according to the analysis of the products collected in the water collector, as a function of the corona current. $[SO_2]$ = 5 ppmV, Q = 2 l/min, diameter of the water collector = 32 mm, V = 10 ml water in it, t = 20 min for each experiment.

3. On the diffusion speed of SO_2 in the water cell.

Some investigations have been performed on the influence of the dimensions of the water sheet used for the pollutants trapping, in particular by changing the diameter of the water sheet while keeping its volume constant (20 ml) and a water height always greater than 3 mm, minimum height found as necessary to absorb the disturbances produced by the electric wind in the water.

Results so obtained on the influence of the area presented to the discharge by the water sheet are illustrated by the Fig. 5. They show that the efficiency of the direct capture of SO_2 by the electric wind (HSO_3^- curve) continues, to some extent, to increase with the diameter of the water cell beyond the area intercepted by the cone of the discharge (cone of ~ 120° angle at its tip and of 15 mm height, that gives a diameter of ~ 50 mm for its surface of interaction with the water). This result is representative of the delay introduced by the diffusion mechanism in the process of incorporation of SO_2 in the form of HSO_3^- inside the water.

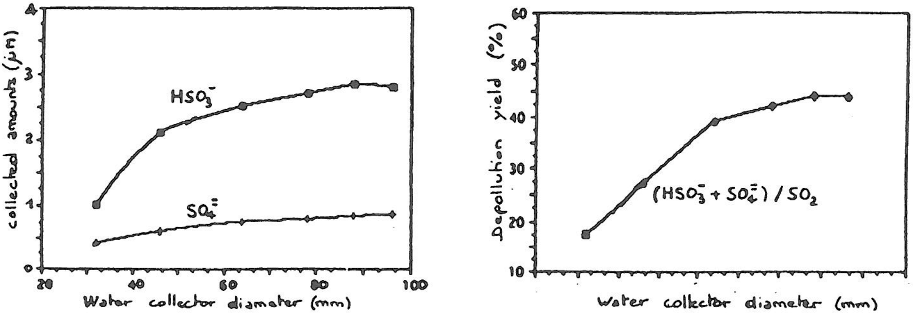

Figure 5. Depollution efficiency as a function of the area presented by the water collector to the discharge. $[SO_2]$ = 5 ppmV, Q = 2 l/min, V = 20 ml water in the water collector, I = 20 µA, t = 20 min for each experiment.

CONCLUSION

In the experiments which have been carried out in this study for the understanding of the processes which could, with the electric wind, be exploited with benefit for corona depollution applications, high relative efficiencies in the trapping of SO_2, about four times more, have been obtained with the electric wind comparatively to the efficiencies obtained by oxidation. However, the experiments performed for this purpose were carried out at low currents (20 µA) and measurements limited to the pollutants effectively trapped in the water cell. To get better depollution yields the current has to be increased and this will lead to a decrease of the relative efficiency of the electric wind since its velocity will increase with the current but in principle more slowly that the oxidation rate. Nevertheless it must be kept in mind that the electric wind corresponds to an intrinsic property of the corona discharge which needs no special energy input and which can, by this fact, only bring an added value to corona depollution processes. Thus, optimization studies must be done in this direction.

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