

N-hexane abatement using a non-thermal plasma

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N-hexane removal is studied in a filamentary plasma produced by a dielectric barrier discharge in synthetic air N₂/O₂ (20%) at room temperature and atmospheric pressure. The influence of various operating conditions such as inlet concentration of hydrocarbon, applied voltage, HV-pulse repetition frequency, and flow rate is examined in terms of n-hexane removal efficiency and by-products formation. Kinetics analysis is done using gas-phase chromatography and real-time mass spectrometry for the detection and quantification of species at the exit of the discharge.

Non-thermal plasmas are now a recognized efficient method for the abatement of VOCs in the context of air depollution [1, 2]. However, it suffers a disadvantage when it comes to by-product formation at low energy deposition in the electric discharge. As a result, plasmas are often combined with another technique (mainly catalysts) to overcome this limitation. The present study is done with the purpose of evaluating and understanding the effect of a dielectric barrier discharge (DBD) on a heavy hydrocarbon in terms of removal efficiency in dry air as well as by-product formation, in view of further coupling to a complementary process.

N-hexane (C₆H₁₄) is selected as the model organic molecule since it is frequently used as a solvent in various industries for different purposes such as extracting vegetable oils and formulating multiple products such as paints and printer inks. The plasma used to remove n-hexane from the polluted air stream is a DBD with a cylinder-rod geometry that is connected to a high voltage (HV) pulsed power supply. The reactor is an alumina tube with a thickness of 2.5 mm and an internal diameter of 10 mm. In the tube's central axis is placed a tungsten rod (diameter of 1 mm), that is connected to the high voltage pulsed power supply, and on its surface is rolled a copper tape that acts as the ground electrode. The discharge volume is 3.89 cm³. The specific energy density, SED (J/L), is defined as the energy deposited in the plasma per unit of volume of the gas stream. It is a function of the deposited energy E (J) per HV-pulse, the repetition frequency f (Hz), and the gas mixture flow rate Q (L/min). The role of these parameters, along with the inlet concentration of n-hexane, is examined and the efficiency of the removal process and the nature of by-products are presented.

By-products and remaining n-hexane present in the treated gas stream are measured using a gas chromatograph and a high-resolution Fourier Transform Ion Cyclotron Resonance (FT-ICR) mass spectrometer (BTrap, AlyXan company). It is able to detect VOCs in trace amounts from tens of ppb with a short response time of a few seconds. The high mass resolution makes it possible to separate quasi-isobaric compounds.

Figure 1 shows the results for n-hexane removal for concentrations between 5 ppm and 215 ppm and for SED = 234 J/L. Under a fixed energy density, the concentration of reactive species created by the plasma does not change. Therefore, when the inlet concentration of n-hexane increases, each n-hexane molecule will have fewer reactive species available to interact with. Hence why the removal efficiency decreases from 61% to 41% when the inlet concentration of n-hexane increases from 5 ppm to 215 ppm respectively, i.e. the less polluted the air stream is, the easier it is to treat.

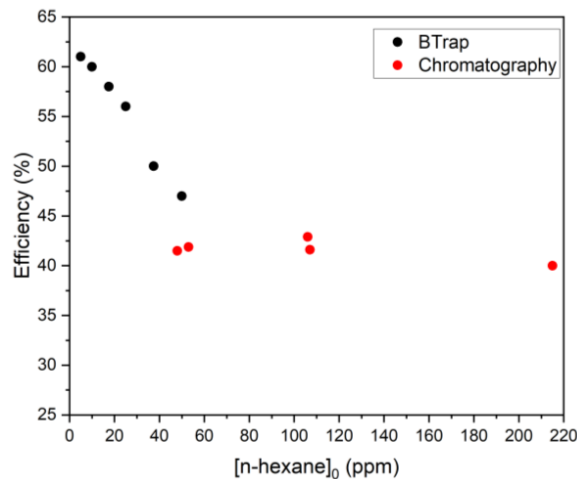


Fig. 1: DBD efficiency as a function of inlet concentration of n-hexane at 234 J/L, 0.5 L/min, 500 Hz

Figure 2 shows the result of n-hexane removal as a function of the SED for two different gas flow rates. In both cases, increasing the input energy resulted in a higher decomposition efficiency of n-hexane, without major influence from the gas flow rate. It exhibits a linear decrease, and we can determine by extrapolation that all of the n-hexane can be destroyed at 0.5 L/min for SED = 600 J/L.

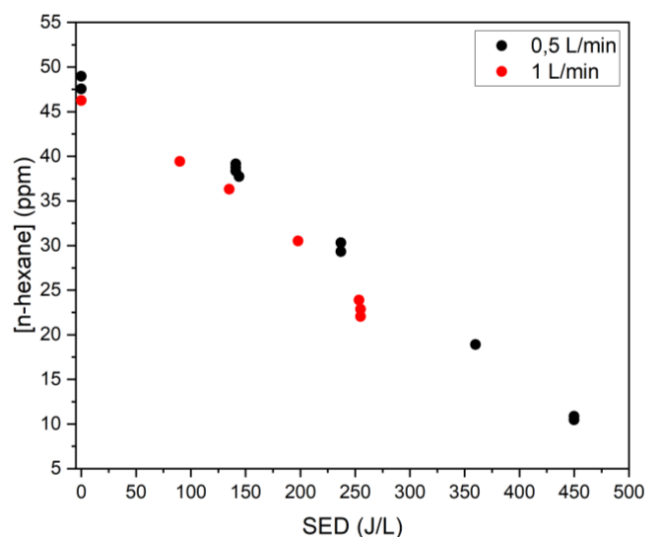


Fig. 2: Effects of SED and gas flow on n-hexane removal at 500 Hz and an inlet concentration of 50 ppm.

The major by-products obtained with the removal of n-hexane from the polluted air stream are formaldehyde (CH_2O), acetaldehyde (CH_3CHO), and propanal ($\text{CH}_3\text{CH}_2\text{CHO}$). For an inlet concentration of 100 ppm and a SED = 215 J/L, approximately 25 ppm of CH_2O and 10 ppm of CO are detected at the exit of the reactor, along with 35 ppm of CO_2 , 5 ppm of CH_3CHO and 1 ppm of $\text{CH}_3\text{CH}_2\text{CHO}$. Over forty other compounds have been detected, all at concentrations inferior to 1 ppm. Their presence can mostly be explained by the oxidation of n-hexane in the air mixture [3], except for two molecules, H_2 and HCN. In their case, a possible formation pathway is through interactions of n-hexane with the metastable states of nitrogen.

References

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