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Field-test at Betonstal Sp. z.o.o. Szczecin/ Poland

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Executive Summary

Field experiments were performed in order to investigate the feasibility of the removal of gaseous styrene (C_8H_8) from the exhaust stream of a polymer concrete production process with means of non-thermal plasma technology. The plasma source and the sensitive laboratory analytical equipment could be applied successful to the industrial process. It is found that styrene could be decomposed almost completely. The main reaction product were formic acid (CH_2O_2) and benzaldehyde (C_7H_6O).

Introduction

The company Betonstal Sp. z.o.o. is located in Szczecin in the North-Western part of Poland and produces various elements made of polymer concrete. The exhaust gas from this production process contains gaseous styrene which up to now is removed by a catalytic process to meet the legislative limitations. The field experiments discussed in this report were performed at the polymer concrete production site close to the process.

Experimental procedure

In Figure 1 the experimental setup is shown schematically. The process gas was flowing through a pipe to the existing exhaust aftertreatment system. For the plasma treatment experiments a sample of the exhaust gas stream was extracted by a pump and directed through the experimental devices (plasma source and infrared spectrometer as well as a dust filter and an active carbon filter for protecting the devices). During the first part of the experiments the plasma source was energized with a compact power source designed and manufactured by Technical University of Szczecin especially for field test purposes. For the second part of the experiments, which mostly is discussed in this report, a programmable AC-HV-power source (Chroma 61604) was used to energize the



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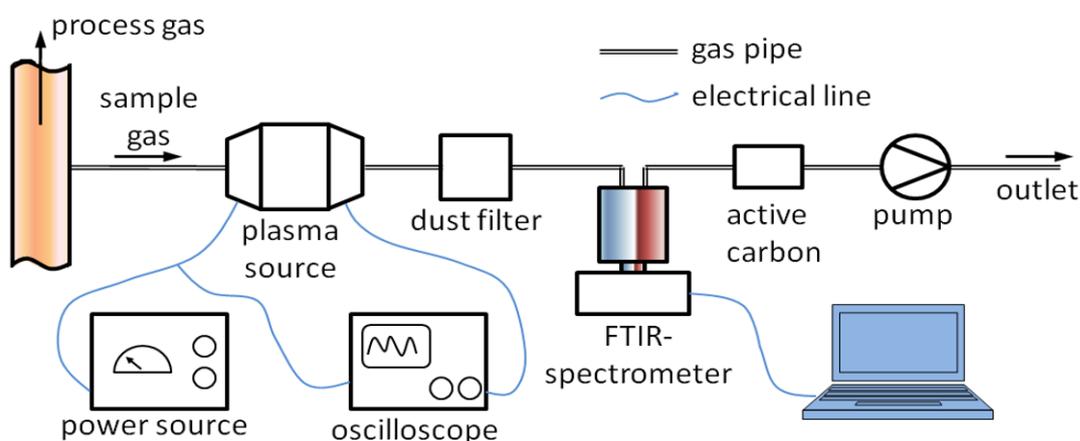


Figure 1: Experimental setup

plasma source. The electrical data were recorded by a digital oscilloscope. The composition of the sample gas was monitored with an Fourier-transform infrared (FTIR) spectrometer with a high spectral resolution of 1 cm^{-1} . The FTIR-spectrometer was controlled by a laptop where the analysis data were stored.

Results

According to the information given by the company the most important pollutant is styrene. Thus, the recorded spectra of the analyzed gas samples were screened for styrene by direct comparison of the sample gas spectrum with a reference spectrum. For illustration, this is shown in Figure 2.

After finding styrene absorption bands in the sample gas spectra the height of the marked peaks was investigated in all recorded spectra and plotted against the spectrum number in order to analyze the temporal behaviour of the relative styrene concentration.

This procedure was also used with several other species found in the sample gas spectra. In Table 1 the investigated components are summarized.

In Figure 3 the temporal behaviour of selected species is displayed for a selected time frame. In addition to the styrene data the behaviour of the ozone (O_3) concentration is given as a "plasma on" marker [1]. Moreover, the data for formic acid (CH_2O_2) and benzaldehyde ($\text{C}_7\text{H}_6\text{O}$) are shown, because these species belong to the main products of the reaction of styrene with ozone [2]. Further products of this reaction are formaldehyde (CH_2O) and benzoic acid ($\text{C}_7\text{H}_6\text{O}_2$) which were not found in the sample gas spectra.

As given in Table 1 the sample gas was also analyzed for the presence of nitrous oxide (N_2O), carbon monoxide (CO), carbon dioxide (CO_2), and water (H_2O). These species are also either plasma or process markers and were used for clarification of the plasma and process status.



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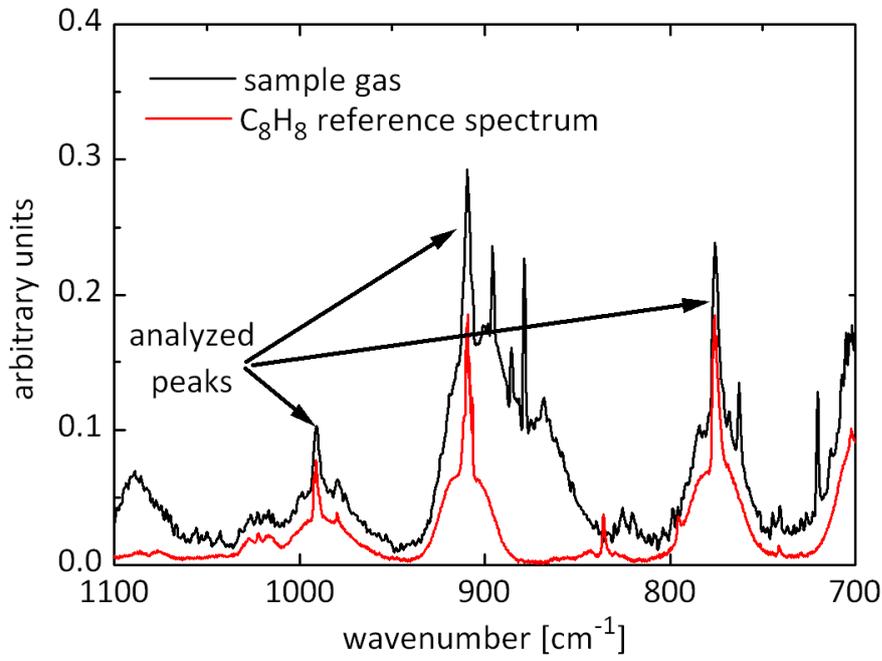


Figure 2: Selected part of an analyzed gas sample and reference spectrum of styrene

name	formula	wavenumber [cm ⁻¹]
styrene	C ₈ H ₈	775.68
styrene	C ₈ H ₈	909.27
styrene	C ₈ H ₈	990.77
carbon monoxide	CO	2107.34
carbon dioxide	CO ₂	2327.04
formaldehyde	CH ₂ O	not found
formic acid	CH ₂ O ₂	1105.23
benzaldehyde	C ₇ H ₆ O	740.6
benzoic acid	C ₇ H ₆ O ₂	not found
nitrous oxide	N ₂ O	2212.58
ozone	O ₃	1053.49
water	H ₂ O	1653.77

Table 1: List of components the sample gas was analyzed for



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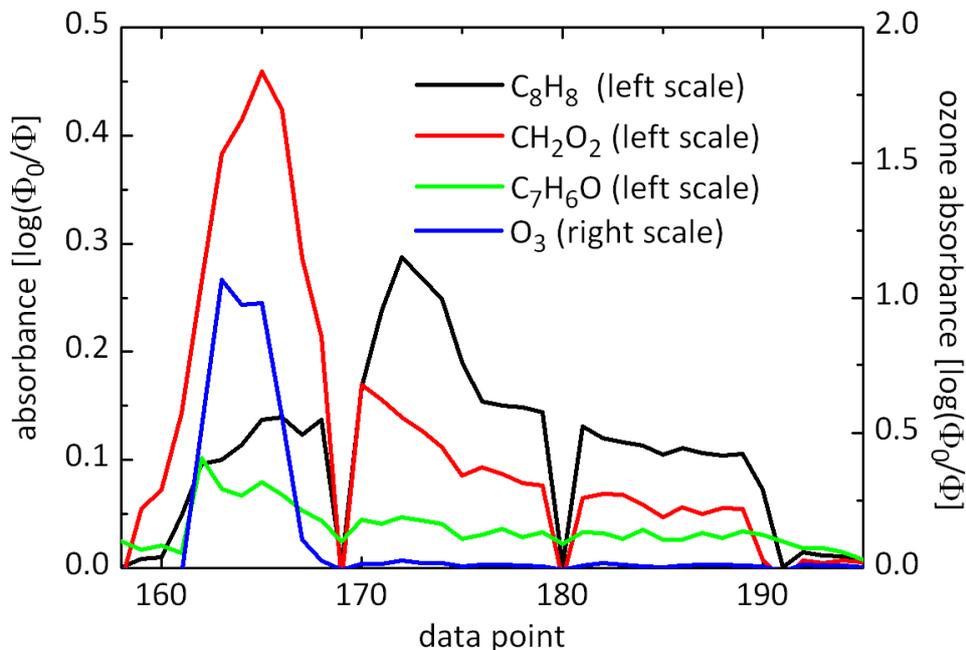


Figure 3: Temporal behaviour of selected species

As can be concluded from Figure 3, switching on the plasma, as indicated by an increasing ozone concentration between datapoint 161 and 167, leads to a decrease in styrene concentration connected to an increase in concentrations of formic acid and benzaldehyde.

This analysis leads to the assumption that the decomposition of styrene by means of non-thermal plasma works and leads to the formation of the expected reaction products additional to CO_2 . The reaction products observed are produced by reaction of styrene with ozone and with hydroxyl radicals [2]. Both are produced by non-thermal plasma operated in humid air.

Taking into account the power input of 150 W and 200 W used in this experiments and a gas flow of about $4 \text{ m}^3/\text{h}$ the specific energy density (SED, power dissipated into the plasma divided by the gas flow) needed to achieve a significant reduction of the styrene content is around 135 and 180 J/L, respectively. This is in good agreement with the data known from the literature [3].

During the analysis of the recorded spectra it was found that the base-line of the spectra sometimes varies. This leads directly to a variation of the height of the peaks which were analyzed. Therefore, it is noted that further studies are necessary for quantitative conclusions.

The feasibility of the effects was further checked by comparing the infrared spectra directly. One example is shown in Figure 4. The infrared spectrum of the untreated exhaust is displayed as black curve and the presence of styrene is clearly visible as indicated by the markers. The red curve shows the infrared spectrum of the plasma treated exhaust gas. The presence of the plasma is shown by the



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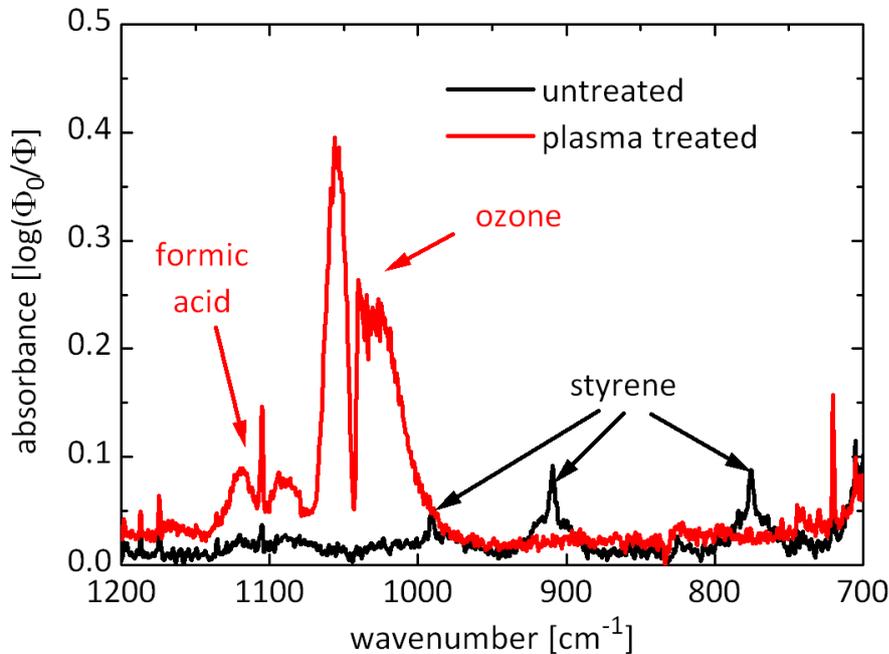


Figure 4: Styrene decomposition by plasma treatment

appearance of the ozone absorption band. The decomposition of styrene is indicated by the vanishing styrene absorption bands and the strong increase in the height of the formic acid absorption band.

For further validation of this results the analysis software of the infrared spectrometer was fed with uncalibrated reference spectra of styrene and ozone and the recorded spectra were processed again. This procedure gives relative values of concentration, but allows to draw conclusions regarding the presence or the absence of the analyzed species.

The resulting concentration trends could be synchronized with the recorded data regarding the plasma and the pump status. We chose a part of the experiments were the pump was sucking gas from the exhaust and the plasma was switched on and off. The data are shown in Figure 5.



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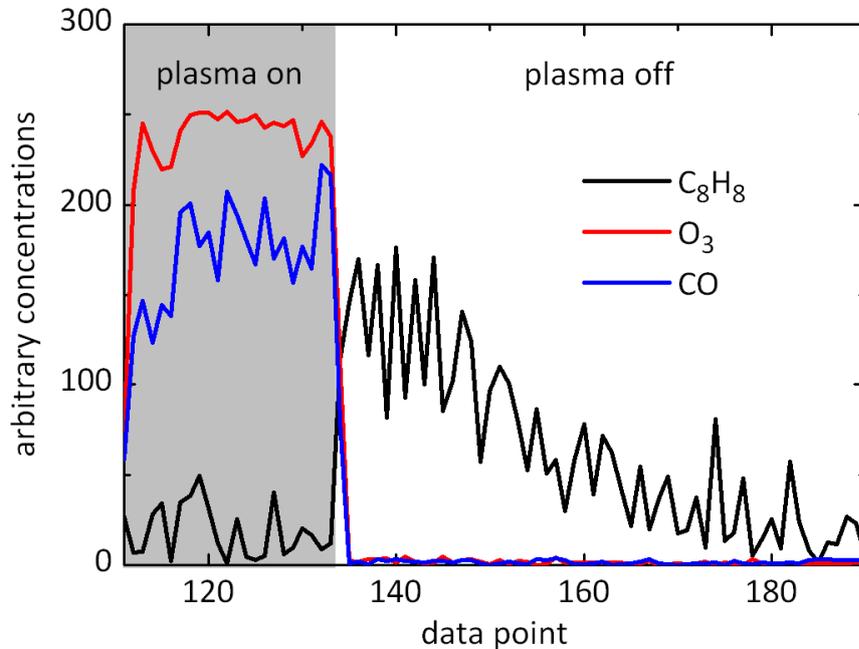


Figure 5: Relative concentrations of selected monitored species

As already found, switching on the plasma results in a significant production of ozone. This correlates with a strong decrease in the styrene concentration. As the data indicate, styrene is removed almost completely. During the "plasma-on-phase" the concentration of carbon monoxide also increases considerably. On the one hand, this is due to the decomposition of carbon dioxide, on the other hand, this also could be due to incomplete oxidation of styrene. This must be investigated more detailed.

Switching of the plasma leads immediately to a drastic decrease in the concentrations of ozone and carbon monoxide, whilst the concentration of styrene increases and then slowly decreases due to the end of the polymer concrete production process.

Conclusions and outlook

Firstly, the experiments demonstrated that the operation of a non-thermal plasma device and quite sensitive laboratory equipment in an industrial production process is possible. The recorded spectral data showed a sufficient sensitivity to the gaseous components of interest.

The results of the analysis of the experimental data shows the feasibility of the decomposition of styrene by means of non-thermal plasma. The study of the spectral data demonstrates the formation of the reaction products as expected from the literature studies. The calculated energy for the decomposition process is in the same range as used in laboratory studies reported in the literature.



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To give reliable statements, including quantitative measurements, regarding the application of a non-thermal plasma device we recommend additional experiments with an experimental setup and procedure adapted to the production process. This will reveal not only the removal efficiency and the energy efficiency of the non-thermal plasma process but give more detailed inside in the formation of reaction products. The treatment of the products already found should also be discussed because there are several possibilities to handle the end-products of plasma-chemical conversion. such findings will be the basis to design an overall gas exhaust treatment process.

Reference

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