EXPERIMENTAL EQUIPMENT FOR TOXIC SUBSTANCES DESTRUCTION USING PLASMA PROCESSING

Coufal O.[1], Gregor J.[1], Hrabovský M.[2], Šenk J.[1], Teplý J.[3]

[1] Technical University, Božetěchova 2, 612 66 Brno, Czech Republic
[2] Institute of Plasma Physics, Za Slovankou 3, 182 11 Praha, Czech Republic
[3] Institute of Analytical Chemistry, Veveří 97, 611 42 Brno, Czech Republic

Abstract. An experimental device for decomposition of organic compounds consisting of a plasmatron, a reactor and a scrubber is described. A temperature and velocity of the medium (carrier gas and/or its mixture with toluene) along the plasmatron and the reactor are determined by solving energy and continuity equations. The effect of reactor entry temperature on the decomposition efficiency for a model compound: toluene, was studied. The efficiency reaches 99.99 % at optimum temperature.

Introduction

One of the methods of destruction of ecologically harmful and toxic substances of organic origin could be high-temperature degradation using plasma processing. This paper deals with the application of the plasmatron with a chemical reactor for toluene decomposition in inert gas. Toluene was used as an example of organic compound for first decomposition study using such type of the device.

Experimental device

A suitable type of plasmatron for heating of the carrier gas is the plasmatron with a two-stage anode. A longitudinal cross-section through the plasmatron is in Fig. 1.

An arc burning from the cathode through the anode channel to its extending part is stabilized by a carrier gas streaming to the plasmatron tangentially in the spaces of the cathode. In the place of the anode extension the character of streaming changes which creates conditions for partial fixation of the arc length. This fixation and intense blasting of the arc causes that the plasmatron has an increasing volt-ampere characteristic in a wide range of current. The plasmatron is supplied by the source of 350 V, 200 A. Basic dimensions of the plasmatron were designed for a carrier gas flow-rate $G_c = 25\ \mathrm{g\,s^{-1}}$. The plasmatron was originally designed for nitrogen as the carrier gas. As hydrogen cyanide could be produced at the interaction of the nitrogen plasma with hydrocarbon, argon was used as the carrier gas.

The values of the following quantities were continuously recorded during each experiment: the current I and the voltage U on the arc, the flow-rate of the carrier gas fed to the inlet part of the anode G_c, toluene flow-rate G_{tol}, temperature and flow-rate of cooling water. The arc voltage with argon as the carrier gas is one third of that with nitrogen as the carrier gas at equal gas flow-rate. The increasing character of volt-ampere characteristics of this plasmatrone type is evident from the dependencies for various anode channel length and argon as the carrier gas in Fig. 2. From the dependencies in Fig. 3 it follows that at the same flow-rate conditions the optimum anode channel length exists. The output temperatures of investigated plasmatron variants determined by solving energy and continuity equations and using measured energy balance and calculated thermodynamic properties are given in Fig. 4.

Toluene was added in the form of vapour (at the boiling temperature of toluene) at the beginning of the reactor (Fig. 5), its velocity was negligible. Power losses on the each part of the device were calculated from the temperature and the flow-rate of cooling water.

Samples of the gas phase for the chromatographic analysis were taken at the end of the reactor (Fig. 5).

Results

Thirteen experiments are evaluated, their experimental conditions are given in Table 1. Toluene amount s in a medium flowing through the reactor is given by

$$s = \frac{100 G_{tol}}{G_c + G_{tol}}.$$

The used method of sample analysis led to identification of benzene, toluene, and other alkylbenzenes. The mass of toluene in the sample to be analysed is m. The mass of toluene added to the reactor that corresponds to the volume of analysed

sample is denoted by m^*. The efficiency of the toluene decomposition is characterized by

$$d = \frac{100(m^* - m)}{m^*}.$$

Other followed quantities are: the mass m_b of benzene in one ml of a sample volume, the benzene/toluene mass ratio r, the mass of other alkylbenzenes and the electric energy W consumed for decomposition of 1 kg toluene

$$W = \frac{100UI}{dG_{tol}}.$$

The energy necessary for heating of toluene to the boiling point and its evaporation is not included in the value of W because it is negligible. The results of the experiments are given in Fig. 6 and Table 1.

Table 1

No.	UI [W]	G_c [g s^{-1}]	s [%]	T_e [K]	d [%]	r	l_2 [mm]	W [kWh kg^{-1}]
I	14 711	10.72	1.06	1 582	79.16	0.36	52	50.1
II	18 193	10.60	1.07	1 794	89.10	0.48	52	52.6
III	17 441	10.87	1.14	1 873	94.14	2.29	68	48.0
IV	18 564	10.87	1.14	1 977	97.60	4.44	68	47.4
V	20 168	10.84	1.15	2 126	98.84	4.84	68	48.0
VI	20 667	10.93	1.14	2 342	99.99	90.00	77	46.2
VII	22 619	10.92	1.14	2 529	99.96	6.67	77	50.1
VIII	24 159	10.91	1.14	2 727	99.82	1.20	77	53.6
IX	28 210	10.90	1.04	2 935	99.68	0.35	103	68.6
X	25 345	10.71	2.80	2 514	99.91	5.25	68	23.0
XI	26 532	10.71	2.88	2 548	99.93	3.50	68	23.2
XII	26 723	10.71	2.88	2 560	99.93	2.92	68	23.4
XIII	27 764	10.73	9.05	2 661	96.51	1.34	68	7.9

Efficiency d of the toluene decomposition increases with the increasing reactor entry temperature T_e from 79.16 % to 99.99 % in the neighbourhood of 2400 K. For T_e >2400 K d decreases with increasing T_e. This effect can be due to recombination reactions in places behind the reactor.

The main new aromatic compound produced is benzene. Its mass m_b in the sample depends on T_e (Fig. 6). From the other aromatic hydrocarbons only xylenes (and ethylbenzene) were found. However, their mass was very low (almost by two orders of magnitude lower than the mass of benzene. For T_e >2300 K this mass is below the detection limit with an exception for the highest temperature value 2935 K.

The toluene amount s in the medium was approximately 1.1 % at the above-mentioned experiments I – IX. The small differencies in s have no effect on the experimental results. E.g. at s =2.80 – 2.88 % the efficiency of toluene decomposition d is the same (compare experiments X – XII in Table 1. But at s value 9.05 % d is lower (see experiment XIII in Table 1). Energy consumed for total decomposition of 1 kg toluene (W) is dependent on the length l_2 of the anode channel, on temperature T_e and on s (Table 1).

The analysis of water in the scrubber proved that about one third of the non-decomposed toluene and hydrocarbons produced is retained in water and two thirds leave to the chimney. At all our experiments a carbon black is generated. A considerable part of carbon black also passes through the scrubber to the chimney.

Conclusions

The possibility of decomposition of an organic compound — hydrocarbon toluene — in low-temperature argon thermal plasma was verified experimentally. The efficiency d of toluene decomposition depends on experimental conditions. The higher is the temperature T_e of argon entering the reactor the higher is d. The percentage of the decomposed toluene reaches the highest value (99.99 %) at approximately 2300 K. Above this temperature d decreases. d also depends on the toluene amount added to the reactor. At high toluene level it is a litlle lower. The content of the main decomposition product benzene in the sample is dependent on T_e, too. The highest content was found at low temperatures. The sum of toluene and benzene mass in the sample is the smallest at the temperature at about 2500 K. It is lower than 0.3 % of the toluene mass added to the reactor. The content of the other aromatic hydrocarbons produced (xylenes and ethylbenzene) is by almost two orders of magnitude lower. A large quantity of carbon black is produced. The obtained decomposition efficiency is an important condition for successful operation of the device for decomposition of organic persistent pollutants.

Acknowledgement

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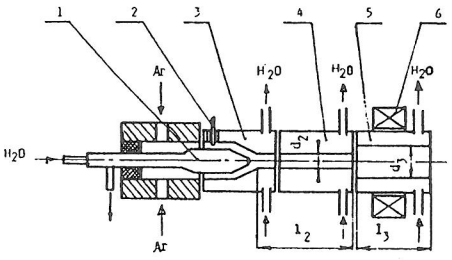

Fig. 1

Schematic picture of plasmatron:
1– cathode, 2– arc iniciated contact,
3– anode input part, 4– anode channel,
5– anode, 6– arc root rotating coil.

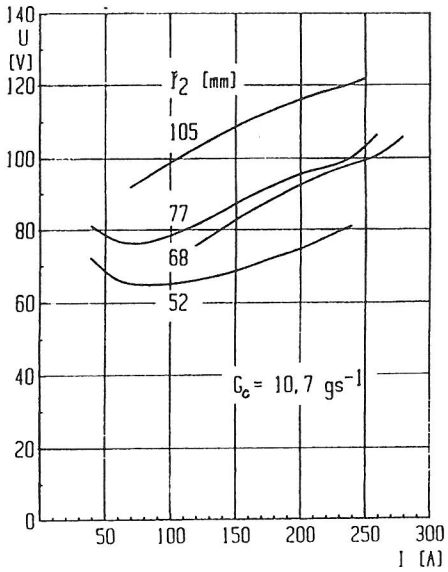

Fig. 2

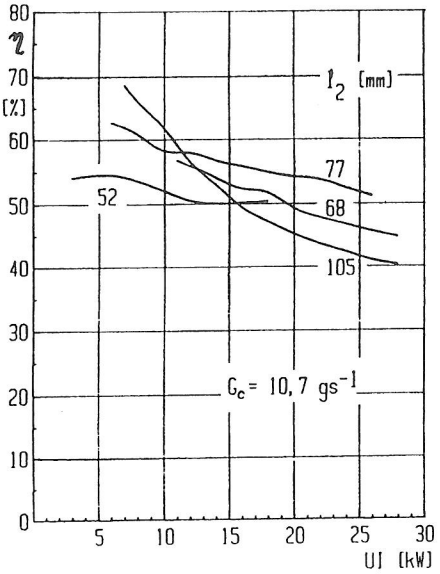

Fig. 3

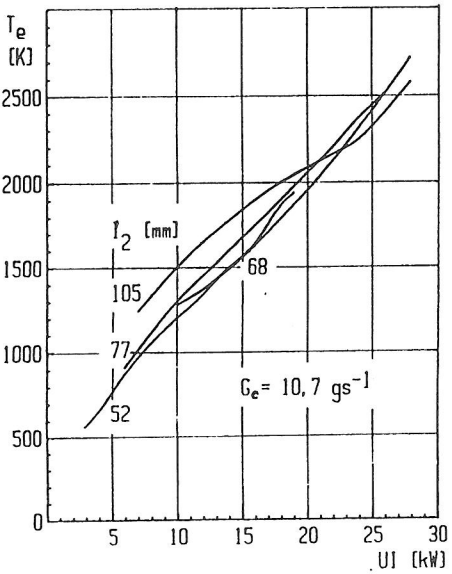

Fig. 4

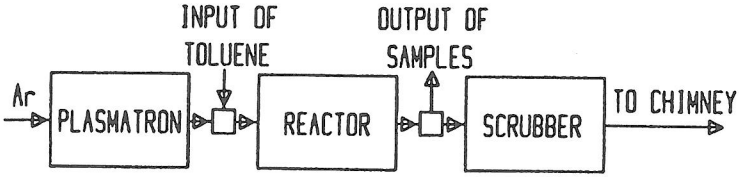
INPUT OF
TOLUENE
OUTPUT OF
SAMPLES
Ar
PLASMATRON
REACTOR
SCRUBBER
TO CHIMNEY

Fig. 5

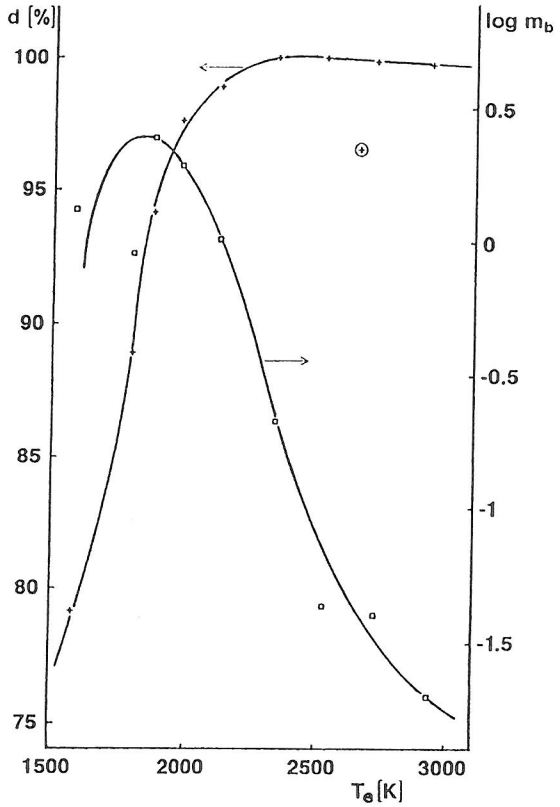
d [%]
log m_b
100
95
90
85
80
75
0.5
0
-0.5
-1
-1.5
1500
2000
2500
3000
T_e[K]

Fig. 6