The destruction of toxic liquid wastes in an induction plasma reactor

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Abstract

The technical feasibility of using the high frequency (hf) induction plasma reactor for thermal treatment of liquid wastes has been studied, using the pyrolysis of toluene as a simulation test of a "waste destruction reaction". The preliminary results are very promising with a Destruction and Removal Efficiency (DRE) greater than 99.9 %, and minimal formation of soot and PAH.

Introduction

DC plasma torch technologies have long been considered for the thermal treatment of toxic liquid wastes, such as the PCBs. Numerous studies [1,2] have been reported in which a wide range of reactor configurations were used, the choice depending on the nature of waste material to be treated. In contrast, far less attention has been given to the application of hf plasma technology for the destruction of toxic liquid materials [3]. This paper will discuss some of the preliminary results obtained for the pyrolysis of toluene in a 50 kW plasma hf unit.

1. Thermodynamic analyses

Thermodynamic calculations of the equilibrium composition for the pyrolysis of toluene were performed by the use of a Gibbs energy minimization program software developed at the Université de Sherbrooke by Lantagne, Marcos and Cayrol [4]. The calculation assumes that the gases are ideal and form ideal mixtures and that condensed species are not miscible. In the process, two different equilibrium regions exist. The first is directly in the plasma, where carbon solid can participate in the equilibrium, as shown in Fig. 1. This simulation shows that the process produces principally C(s), H_2 and C_2H_2. However, at the plasma torch exit (i.e. in the reactor), the solid carbon deposits on the wall and it is unable to participate further in the equilibrium reactions. For this region, the Fig. 2 (simulation without C(s)) describes the system equilibrium more satisfactorily. By comparing experimental gas compositions and the thermodynamic predictions, Fig. 2 shows that good agreement is achieved with the experimental results when the production of C(s) is weak (as in trials with water steam where no condensed phases are present) . On the other hand, the presence of solid carbon (as was present in trial E from the Table 1) can be explained by the use of the Fig. 1, although the PAH presence in the solid residue has to be estimated by the use of the Fig. 2. These results are in good agreement with other researches [5].

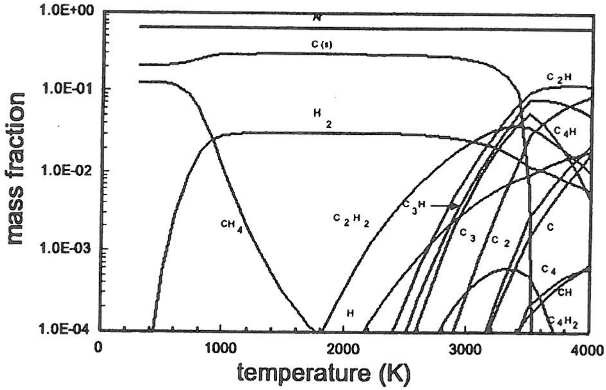

Figure 1 : Equilibrium composition at 1 atm for an Ar-C-H mixture, C / H = 0.8, taking into account solid carbon

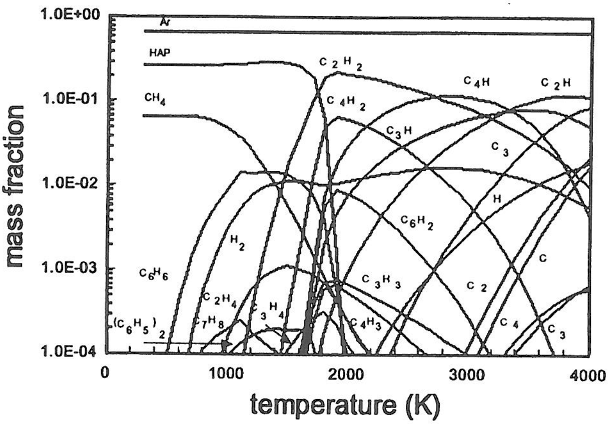

Figure 2 : Equilibrium composition at 1 atm for an Ar-C-H mixture, C / H = 0.8, without C(s)

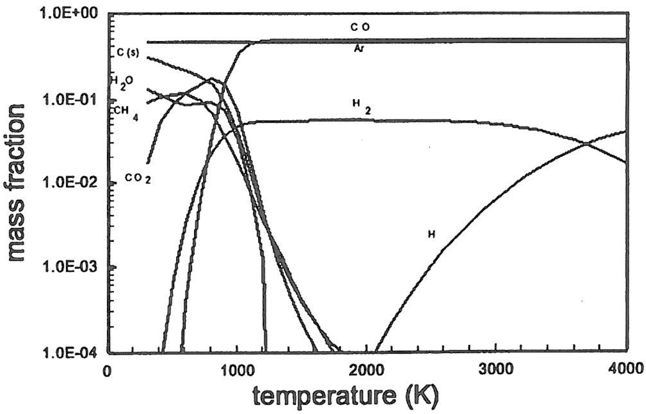

Figure 3 : Equilibrium composition at 1 atm for an Ar-C-H-O mixture, C / H = 0.31, with C(s)

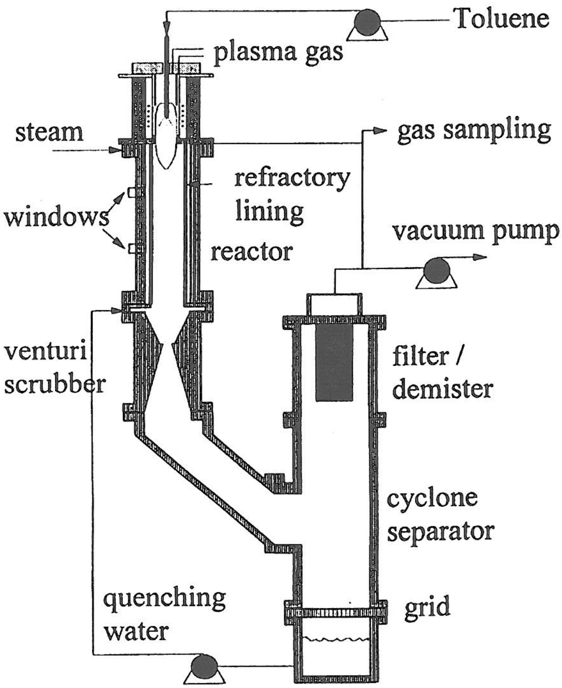

Figure 4 : Experimental plasma reactor set up

2. Experimental

The process reactor set up is shown in Fig. 4. The simulated "liquid waste" is sprayed directly into the center of the plasma through a water-cooled atomization probe introduced into the coil region of the plasma torch. The spray is obtained by means of a plain-jet "airblast" atomizer, using Argon as the atomization gas. The plasma gas flowrates employed are : central gas / 30 slpm (Ar) and sheath gas / 90 slpm (Ar) + 9 slpm (H_2). An inert atmosphere is maintained within the reactor to avoid the formation of dioxins, furans and NO_x by side-reactions. The pyrolysis reactions are carried out in a water cooled wall reactor. To reduce the tendency for sooting and to minimize the PAH formation, saturated steam is injected into the reaction gas at the exit of the plasma torch. The water vapor combines with carbon to form CO (see Fig. 3). The fume from the pyrolysis is quenched and cleaned in a venturi scrubber and the fine particles are captured on a filter. For environmental reasons, the reactor system is kept under a slight negative pressure (80 kPa) and the scrubbing water is recirculated. The "off gas" is characterized by two devices, a gas chromatography (Hewlett Packard 5880A) for H_2, CH_4, C_2H_2, C_4H_2, CO, CO_2 and a gas chromatograph electron ionization detector (Hewlett Packard GCD system G1800A) for C_7H_8 , C_6H_6 and PAH.

3. Results and discussion

Preliminary results of this work are presented in the Table 1. From these results and the previously discussed thermodynamic equilibrium analyses, the following observations are made : 1) to obtain a high DRE the reactor temperature is the key parameter and must be maintained at as high value as possible. By comparing the trials A, B, F and G from the Table 1, it can be noted that DRE increase as the reactor temperature increase. 2) to reduce sooting and the PAH formation (as shown by the Fig. 3), steam must be injected during the pyrolysis of the toluene : the trial E from Table 1 was performed without steam and has presented a high content of PAH and a large production of soot (2.62 g / min of C(s), produced with a feed rate of 3.4 g / min of C_7H_8). 3) to obtain a good DRE and also to minimize the PAH formation, the atomization must be fine (see trial D from the Table 1), 4) as illustrated in the Fig. 5, the process produces a carbon black aggregate containing a low concentration of organic matter (% of organic matter < 0.007 % (w/w)) , 5) the thermodynamic analyses provide a crude estimate of the composition of the process products but the results must be interpreted with care because we have two different regions of equilibrium and the quenching temperature for the gas is not unique. As mentioned before, the agreement between thermodynamic and experimental compositions ,where no condensed phase is present, are very good, as illustrated by the trial G from Table 1. Equilibrium compositions at 2000 K are : 83.06 % Ar, 12.58 % H_2 , 4.20 % CO, 0.0063 % CO_2, < 0.0001 % C_2H_2. and 0.086 % H_2O.

Table 1 : experimental results

runs #	A	B	C	D	E	F	G
$\dot{m}_{C_7H_8}$ (g/min)	6	6.7	11.5	3.4	3.4	3.4	3.4
$\dot{m}_{H_2O}$ (g/min)	10	12	24	8	0	10	10
reactor (cm) length diameter	 100 8	 100 8	 100 8	 100 8	 100 8	 29 7.6	 29 7.6
refractory	no	yes	yes	yes	yes	yes	yes
water quench	yes	yes	yes	yes	yes	yes	no
power (kW)	40	40	40	40	40	40	40
pressure (kPa)	80	80	80	73	73	73	73
composition	of	the	gas	(% v/v)			
Ar	----	----	----	84.47	86.97	83	82.3
H_2	----	----	----	11.41	12	12.03	13
CO	----	----	----	2.33	----	3.03	3.5
CO_2	----	----	----	0.34	----	0.59	0.52
C_2H_2	----	----	----	0.12	0.32	0.08	0.013
C_4H_2	----	----	----	0.006	0.01	----	----
CH_4	----	----	----	0.61	----	0.57	----
H_2O	----	----	----	0.71	0.7	0.7	0.7
$\dot{m}_{C(s)}$ (g/min)	----	----	----	0.57	2.62	~ 0	~ 0
DRE (%)	**[99.927-99.940]**	**[99.940-99.951]**	**[98.427-98.713]**	**[29-42]**	**[99.165-99.317]**	**[99.787-99.825]**	**> 99.99**
comments		refractory lining temperature ~ 600° C		without atomization gas ("drop by drop")	injection of saturated toluene at the torch exit		refractory lining temperature ~ 800° C

4. Conclusion

The destruction of toxic liquids in a hf plasma reactor with the co-injection of steam have been investigated and the preliminary result are quite encouraging : DRE > 99.9 % and no toxic solid residue produced. Further work will be performed in the near future on the optimization of the reactor temperature and the steam / Toluen mixing conditions.

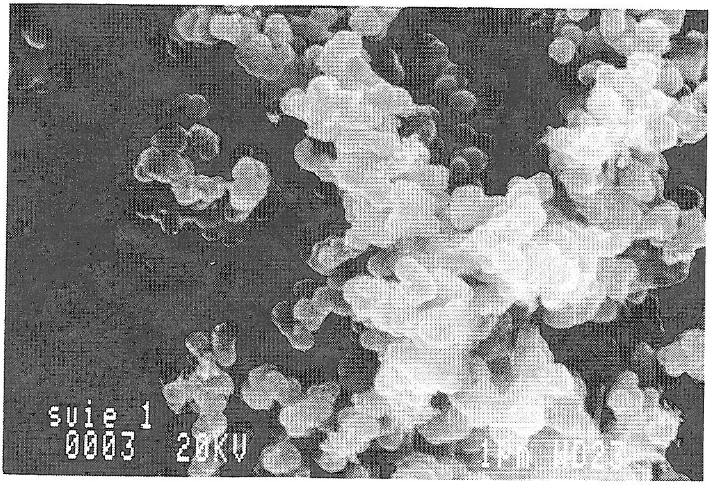

Figure 5 : Carbon black aggregate from run # E

Acknowledgments

The authors gratefully acknowledge the financial support of the Conseil de Recherche en Sciences Naturelles et en Génie du Canada (CRSNG) and the Québec Fonds pour la Formation de Chercheurs et l'aide à la Recherche (FCAR).

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