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VOLATILE AND SEMIVOLATILE COMPOUNDS FROM THE PYROLYSIS AND COMBUSTION OF VISCOELASTIC MEMORY FOAM

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Introduction

Viscoelastic memory foam (VMF) is a polyurethane-based foam with additional chemicals to obtain a material showing both viscous and elastic behavior at the same time. This type of foam presents the ability to distribute the weight over all surface, being mainly used to manufacture mattresses and pillows in order to provide products which can prevent health problems related with the lack of sleep. The increase of sleeping disorders in the population has involved that the memory foam mattress market has grown 20% in the past eight years, meanwhile for the next three years the expected trend is to achieve the annual increase of 7%.

Mattresses waste management is a big problem because of their high volume. They are not desirable items for landfilling and their recycling involves economic drawbacks. These facts, together with the high caloric value of this type of waste, make the waste-to-energy the best disposal option. To optimize this management method it is necessary to know the kinetics of the decomposition of VMF, which has been reported previously[1], and the pollutant formation under different conditions.

The present work aims to characterize the emissions from pyrolysis and combustion of VMF waste at different temperatures, mainly focusing on the analysis of gases, light hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and Polychlorobiphenyls (PCBs).

Materials and Methods

VMF was collected from a landfill in Alicante (Spain) and the data from the characterization of the sample are shown in Table 1.

All experiments were performed in a horizontal tubular-quartz reactor shown in the Figure 1, where reactor is situated inside an electric furnace and the system allows to introduce the sample trough the reactor at controlled speed (0.21 mm/s).

Nitrogen and synthetic air (flow rate of 350 mL/min) were used in pyrolysis and combustion experiments, respectively. Four different temperatures (550, 650, 750 and 850ºC) were selected in order to study the decomposition products under different operating conditions. The sample amount employed corresponding to slightly substoichiometric oxygen condition (the air flow used was around 80% of the necessary stoichiometric air flow) favoring the formation of compounds of incomplete combustion at 850ºC (180 mg of VMF).

Three different series of experiments, as well as blank runs, were carried out for each experimental condition to collect the different compounds. Gases and volatile compounds were collected in Tedlar® bags and analyzed by GC-TCD and GC-FID. The eight experiments, were repeated to analyse PAHs by HRGC-MS in SCAN mode, according to U.S. EPA method 8270D. Finally, PCBs (from at 1 g of sample burnt) were analyzed by HRGC-HRMS, according to the standard method for its chlorinated analogues U.S. EPA method 1668C.

Results and Discussion

Table 2 shows the results corresponding to gases and light hydrocarbons yields obtained in pyrolysis (P) and combustion (C) runs at four different temperatures (550ºC, 650ºC, 750ºC and 850ºC). A part form CO_2, CO was one of the main gases emitted not only in combustion but also in pyrolysis of VMF, which are common products from the thermal decomposition under an inert atmosphere of polymers such as polyurethanes[2], increasing the yields of both with the temperature. On the other hand, in combustion runs CO_2 presented a maximum at 850ºC whereas the CO did so at 750ºC.

Regarding light hydrocarbons, the largest yields corresponded to ethylene, methane, ethane, propane, 1,3-butadiene and acetylene, in this order. Under pyrolytic conditions light hydrocarbons shown in general higher total yields than in combustion which means that these compounds are easily oxidized under an oxidative atmosphere. Ethane, ethylene and propane shown the maximum at 650ºC, not only in pyrolysis but also in combustion; methane presented the highest value in pyrolysis at 650ºC and combustion at 850ºC and acetylene the maximum yields were detected at 850ºC and 750ºC in pyrolysis

and combustion, respectively. Pyrolysis at 650ºC, 750ºC and 850ºC, in this order, shown the largest light hydrocarbon total yields, whereas the values obtained in the rest of runs were of the same order of magnitude.
Total yields of the 16 priority PAHs are shown in Figure 2 where it can be observed that the runs performed at 850ºC presented the maximum values in combustion and pyrolysis. In general, the total yields rose with the temperature for both atmospheres, except for combustion at 550ºC and 650ºC where there was a slight decrease. The number of PAHs detected also increased with the temperature because only in the pyrolysis and combustion at 850ºC were all 16 priority PAHs detected. For temperatures lower than 850ºC, the total emissions in combustion experiments were higher than those in pyrolysis, however, the opposite behavior it was found at 850ºC where the total yield in pyrolysis was around 9000 ppm, whereas in combustion was around 7000 ppm.
Naphthalene was the most abundant compound in almost all runs expect in pyrolysis at 550ºC were fluorene was the predominant PAHs detected. Following naphthalene, fluorene and acenaphthylene were the second most important products in pyrolysis and combustion runs, respectively, in all runs.
Total yields and total WHO-TEQ levels of PCBs are shown in Figure 3 where it can be observed that the total yields in pyrolysis runs were much larger than the combustion experiments at the same temperatures, the most important difference being detected in the runs at 650ºC. The evolution with the temperature was different depending the atmosphere employed, meanwhile in combustion there was a decrease with the rise of temperature, under pyrolytic condition a maximum value was detected at 650ºC decreasing more than 400 pg/g from this temperature up to 850ºC.
As was expected observing the total yields, the WHO-TEQ levels followed a similar trend with a maximum in pyrolysis at 650ºC and a decrease with the temperature in combustion, except in combustion run at 850ºC. In this experiment the WHO-TEQ yield rose respect to combustion at 750ºC and also was higher than the value detected in pyrolysis at 850ºC. This fact can be explained analysing the congeners profile presents in Figure 4 where the PCB-126, which is the most toxic polychlorobiphenyls, was detected with the highest level in combustion at 850ºC.
Regarding to the distribution of PCB congeners shown in Figure 4 the PCB-118 was the most abundant product in almost all experiments except in combustion at 850ºC where the PCB-77 was the predominant.

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References:
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2 O. Terakado, H. Yanase and M. Hirasawa, (2014), Journal of Analytical and Applied Pyrolysis 108, pp. 130-135.

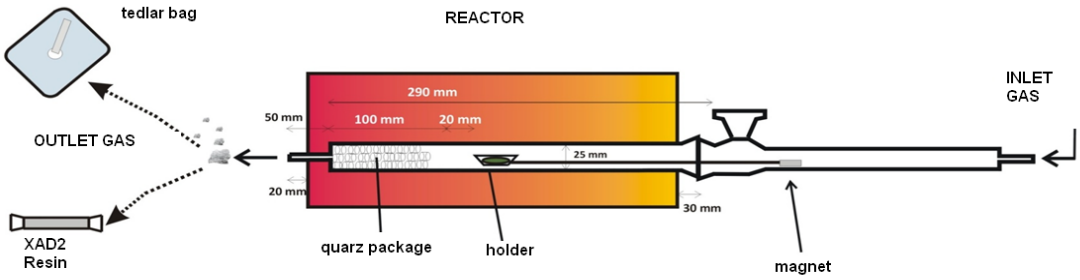

Figure 1. Scheme of the reactor inside the furnace.

Table 1. Data from the characterization of the foam.

NCV (MJ/kg)	27.13
Moisture (%)	1.30
Volatile matter (%)	99.73
Ash (%)	0.11
C(%)	61.26
N(%)	3.34
H(%)	8.45
S(%)	0.16
O by difference (%)	26.68
Cl^- (mg/kg dry mass)	117

Table 2. Gases and volatile compounds from the pyrolysis (P) and combustion (C) of viscoelastic memory foam at four different temperatures.

EXPERIMENT	**P 550**	**P 650**	**P 750**	**P 850**	**C 550**	**C 650**	**C 750**	**C 850**
COMPOUND	mg compound/kg sample (ppm)							
Analysis by GC-TCD								
H_2	521	1753	2897	7383	nd	nd	nd	nd
CO_2	5826	32058	38595	102099	1241035	1379824	1632718	1919688
CO	3000	39297	55554	81358	248356	367658	425903	245279
R_{CO}=CO/(CO+CO_2)	34%	55%	59%	44%	17%	21%	21%	11%
Analysis by GC-FID								
methane	10344	122750	68738	76546	9387	20273	19784	22201
ethane	5410	46186	11661	5319	1759	4165	2709	1225
ethylene	23007	131358	73474	91236	21336	37467	31705	29421
propane	1854	7774	1097	252	345	690	318	47
acetylene	30	442	678	4040	956	1538	1982	110
1,3-butadiene	280	3668	4148	3153	nd	nd	nd	nd

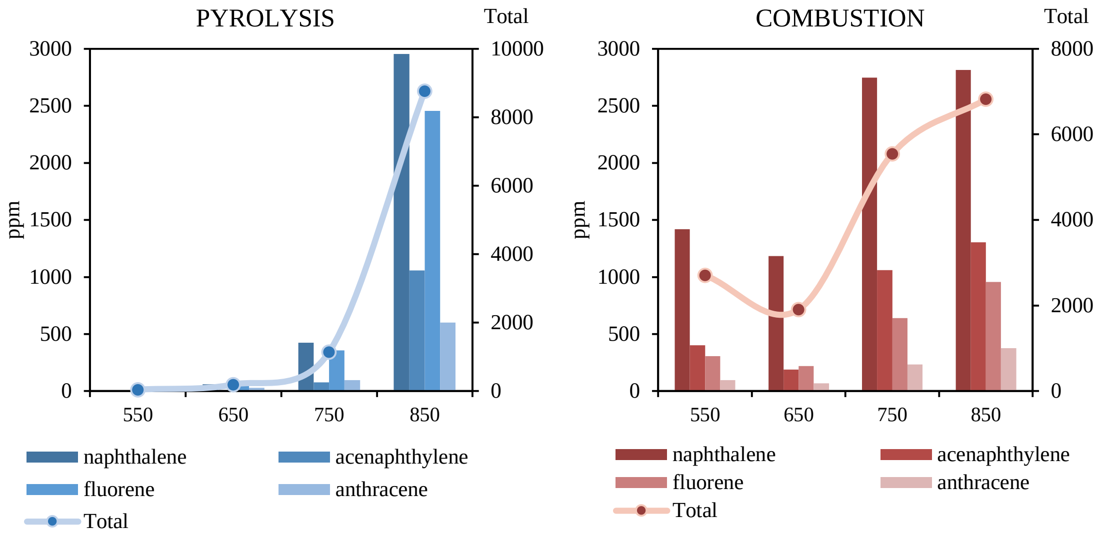

Figure 2. Profiles of the most abundant 16 priority PAHs detected and the total yields in pyrolysis and combustion runs at four different temperatures of viscoelastic memory foam.

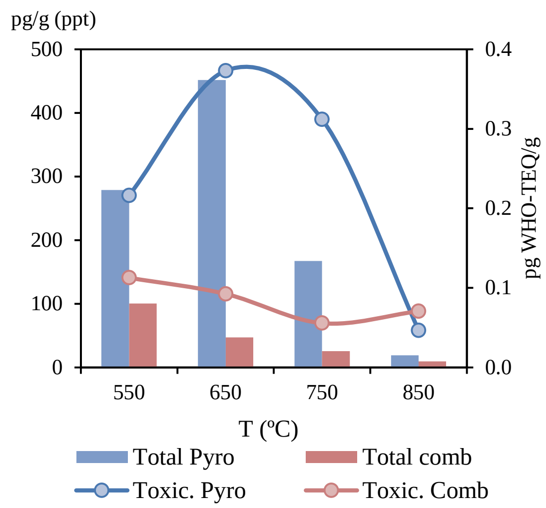

Figure 3. Total yields and total WHO-TEQ yields of PCBs in pyrolysis and combustion at 550, 650, 750 and 850ºC of VMF.

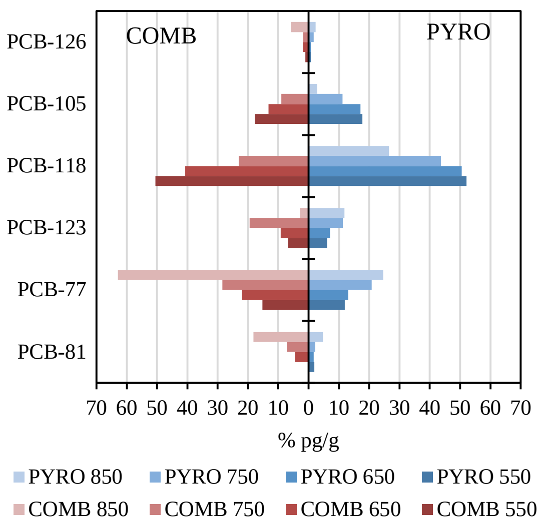

Figure 4. PCBs profiles in pyrolysis and combustion at four different temperatures of VMF.