A LAB-SCALE MICROWAVE SYSTEM FOR EXPERIMENTS OF HIGH TEMPERATURE WASTE PYROLYSIS

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Introduction

The waste that contain non-recyclable organic substances can generate **energy and useful by-products** if processed by **thermal techniques.** This kind of conversion is the only one that is effective in decomposing techno-polymers, rubber, leather, sludge and like into fuel gases, liquids, and solids.

The term ***thermal*** includes combustion, gasification, and pyrolysis.

For instance, in the management of WEEE (Waste of Electrical and Electronic Equipment), reductive thermal treatments like pyrolysis and gasification aim mainly at recovering fractions useful for their fair heating value (~18 MJ/m^3) (Li et al., 2011).

There are **constraints for reductive thermal processes of WEEE**, however. A few of them (taken from Hense et al., 2015) are summarized in the **Table below.**

Aims / T range, °C	Cracking bigger mol_s; preventing PBDD/F prod.	Not forming halo-derivatives; favouring HBr instead	Metals not volatilized, retained in *char*	Producing light HC and permanent gases
600 and over			Possible formation of MeBr	
580				
500				
450 (thresh.)				

The table of melting points below (degrees C) shows which are the **relevant metals that are critical for process temperature selection.**

Tin	232	Aluminum	660	Copper	1084
Lead	327.5	Silver, Pure	961		
Zinc	419.5	Gold, 24K Pure	1063		

We can conclude that when dealing with complex waste, one would have to **decide between a narrow range of *compromise temperatures* around 600 °C, or** – quite the other way – **the most suitable T for 1 selected target component.**

The MW Lab-scale system setup designed and assembled

The reactor designed and assembled at *Università degli Studi di Palermo* **- presented here - was rather conceived to explore**

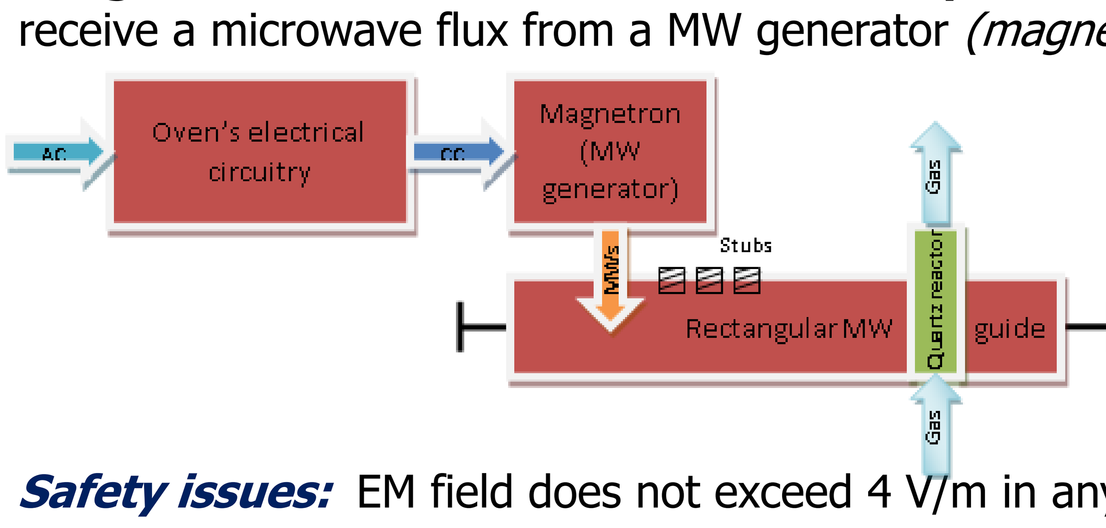
- **high unit power input, high temperature processes;** applied to
- **waste free of low-melting or boiling metals.**

Its main field of use therefore is likely to be the *destruction* of liquid waste fed as an aerosol; or of VOCs; or of granular waste making a fluidized bed. If required, a 3-phase system including a solid catalyst could also be set up.

Non-thermal plasmas (NTP) for VOC abatement

What is a non-thermal plasma? After Vandenbroucke et al. (2011), non-thermal plasmas are generated by applying a sufficiently strong electric field to ensure the discharge of a neutral gas.
Due to their light mass, electrons are selectively accelerated by the field and gain high energies while the heavier ions remain relatively cold through energy exchange with the background gas.
The generation of NTP at atmospheric pressure and ambient temperature has been the subject of many research papers during the last two decades.
The most extensively studied target compounds – sort of benchmarks, actually - are trichloroethylene, benzene and toluene.

At University of Palermo **a Microwave (MW) pilot system has been designed, set up and tested. Its core consists of 2 rectangular waveguides with flanges, fastened in series, in which a quartz reactor can be placed** and receive a microwave flux from a MW generator *(magnetron)* rated at 1 100 W.

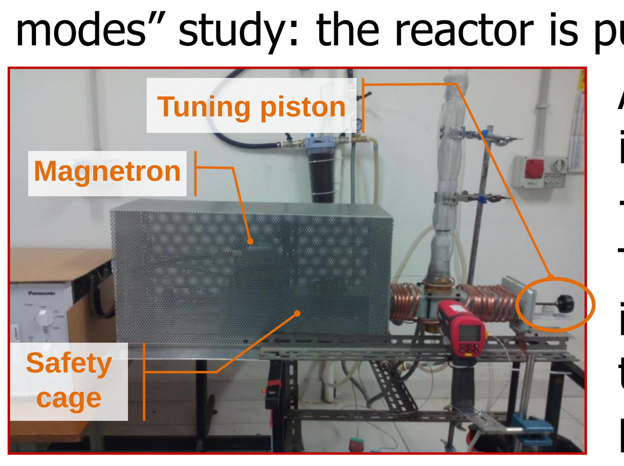


The power input is 800 W, adjustable in 5 steps; the frequency is the customary 2 450 MHz, that is about 20 times the RFs which are used by several Authors.

Safety issues: EM field does not exceed 4 V/m in any point of the surrounding lab area.

Materials and methods

Basically, the system described here was made as a ***single-mode cavity*** that can be tuned turning 2 end pistons and 3 stubs placed in the two waveguides. The antenna inlet and the hole for the quartz reactor were placed after a "resonant modes" study: the reactor is put where the electric field is strongest.

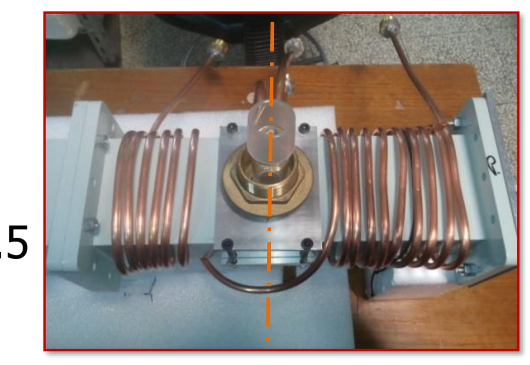


A single- (or mono-) mode cavity is a resonant cavity in which no MW reflection occurs except – in the case - those due to the interfering presence of the sample.

The advantage is that it can generate a much higher intensity of EM field than the multi-mode cavity, therefore is more favourable for fast heating processes.

More, no *dummy load* nor *terminator* are required to absorb and dissipate excess energy. The setup cost less than 6 000 euro for the materials only.

The quartz reactor, in which to put the sample, was designed specifically for the pilot system. It has an outer diameter of 25 mm and is placed vertically into a hole drilled in the waveguide; it lets into a Liebig condenser.



The bottom of the reactor is fitted with a quartz tube (O.D. 8 mm) for input of the process gas flow.

The fine tuning of the system's frequency is done with three stubs located in one of the two waveguides.

A Network Analyzer working in the range 50 MHz ÷ 13.5 GHz (MW power: ≈ 5 dBm) was used to measure the resonance frequencies.

A fan was placed near the magnetron to dissipate the heat generated during operation. The waveguide around the reactor is cooled by a copper coil, wound onto it and filled with circulating cold water.

• *The gas line*

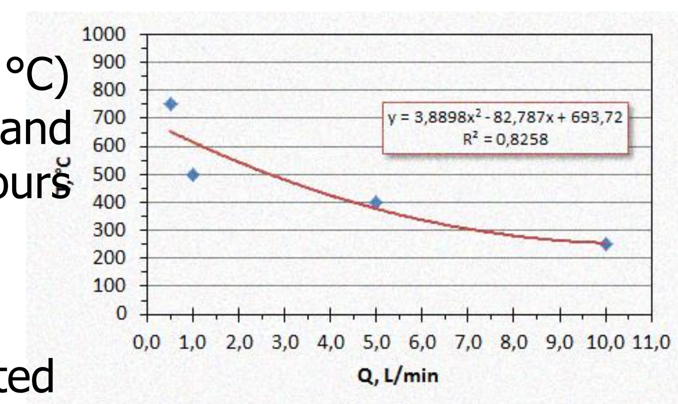
The output gas line involves refrigeration and condensation of the gaseous products. To capture non condensable volatile compounds, in the effluent gas, traps of methyl or ethyl alcohol and of chloroform are provided.

Air sampling bags are suitable to sample the gases for following gas-chromatographic (GC) analysis. For oil products, a GC-MS analysis is planned.

• *Process variables*

Pyrolysis is a chemical process of thermal decomposition of organic components in an oxygen-free atmosphere to yield *char*, *tar* and gas.

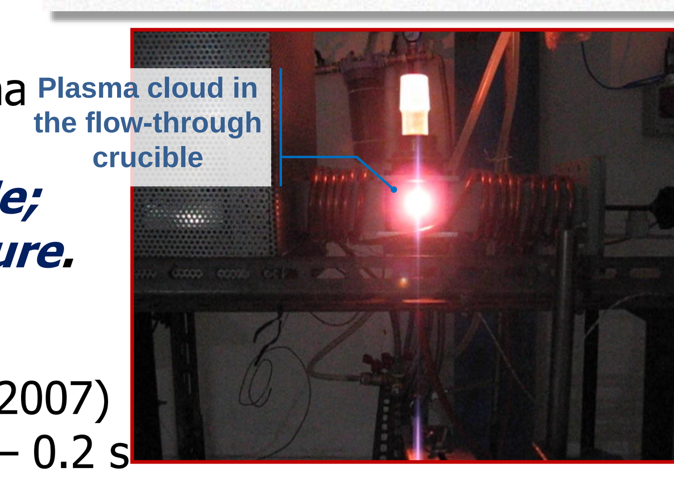
For a given waste composition, Unit Power supplied (W/kg of sample); temperature reached; flow and nature of inert gas used; and residence time in the reactor, are the main process variables (see picture below).



For instance, the use of high temperature (> 500 °C) gives rise to high gas yield, due to to gasification and secondary cracking reactions of the pyrolysis vapours (Domínguez et al., 2006).

Results and discussion

The pilot system at *University of Palermo* was tested and found able to focus into a quartz reactor a very high energy density, up to generate plasma state in 10 s from its switching on.



Sample: blank of granular graphite; Gas: He; Residence Time = 30 s; atmospheric pressure.

This should be taken just as a first trial.

Other Authors indeed (Kim et al., 2006; Mizuno, 2007) have reported of Residence Times as low as 0.1 – 0.2 s to destroy 200 ppm toluene in air flow in a catalytic reactor (Ti or Al oxides).

Conclusions

The mono-mode MW cavity for lab-scale experiments on different types of waste realized at *Università di Palermo* (Teams in Sanitary and Environmental Engineering, and in Physics) enables those researchers to develop an investigation on the ability of MW-Induced Pyrolysis (MIP) to destroy dangerous and toxic substances.

In making comparisons with other plasma systems, it ought to be kept in mind that MIP systems offer the **advantages** that there are neither metal surfaces exposed to the reaction, nor high – potential wiring laid around the reaction tubular vessel.

An issue still open about MW systems – all the more so for the MW – plasma ones – is the **scale-up of the complex waveguide – reaction vessel.** The basic criterion should be keeping the electric field uniform in the reactor; in plasmas the shielding effect of MW by charged particles is an additional complication.

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