Microwave destruction of trichloroethylene in a H_2O - O_2 - Ar plasma

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Background

- As of 1997, solvent usage increased to roughly to 6.5 X 10^6 tpy
- Toxic air contaminants (TAC)may produce toxic by-products while undergoing capture and treatment. Chlorinated solvents, chlorofluorocarbons and sulfur hexafluoride fall into such a category because of their higher activation energies and low biodegradability under oxidative conditions
- An increase of about 67% (16 X 10^6) tpy has occurred in the emissions of HCFCs, PFCs, and SF_6 during the decade of the 1990's
- Although increases in emissions have occurred, concentrations of emitted streams may actually be decreasing because of improved production methods or capture of these pollutants

Background

- Control costs generally increase as concentrations decrease, e.g., the cost of catalytic incineration of VOCs increases from about $5,000/ton to $50,000/ton for a compound such as benzene as its concentration drops from 100 ppm_v to 10 ppm
- Control costs for NO_x range from roughly less than about $1000/ton for advanced burner technologies to over $5,000/ton for exhaust gas treatments
- Development of efficient control strategies for low concentrations of these compounds while avoiding NO_x formation is highly desirable
- Adsorption is an efficient and economical method for moderate to low concentration streams. Nevertheless, adsorbates (such as VOCs) must be removed periodically after they saturate the adsorbents (e.g., activated carbon or zeolites) and require further treatment

Sorbent regeneration

- Conventional regeneration methods: steam and hot gas - first needs steam source, leaves wet bed; second requires high flow rates, large energy demand to heat whole system
- Microwave regeneration utilizes "dielectric heating" which eliminates many of the above drawbacks

Advantages of microwave processing of VOC‘s

- Production of high ionization levels and molecular dissociation without excess heating of the contained gas
- Construction of reaction vessels which are simple, free from contamination and less subject to damage because of the absence of internal electrodes
- Production of little electrical interference
- Absence of high voltages which can be easily contacted by operating personnel, i. e., absence of shock hazardous
- Potentially lower power consumption
- The ability to tolerate high concentrations of water - maybe less NO_x

Experiments

- Microwave source
  - Continuous microwave generator(low ripple magnetron, 1.5 KW, 2450 MHz; Gerling Laboratory) and a plasma tuner (ASTEX) generate a steam plasma
  - Main components of the system consisted of a plasma reactor (AX 7200), a plasma tuner, microwave generator and microwave wave-guide
  - Continuous microwave power from the magnetron conducted through a waveguide to the plasma torch.
  - Forward and reflected powers from the plasma torch maximized and minimized by adjusting the tuning stubs on the plasma tuner. Forward power maintained typically at 600W and the reflected power was maintained below about 100 W.

Experiments

- The plasma reactor consisted of a 1/4" O.D. ceramic tube through which the mixture to be reacted was passed, and an outer quartz tube housing

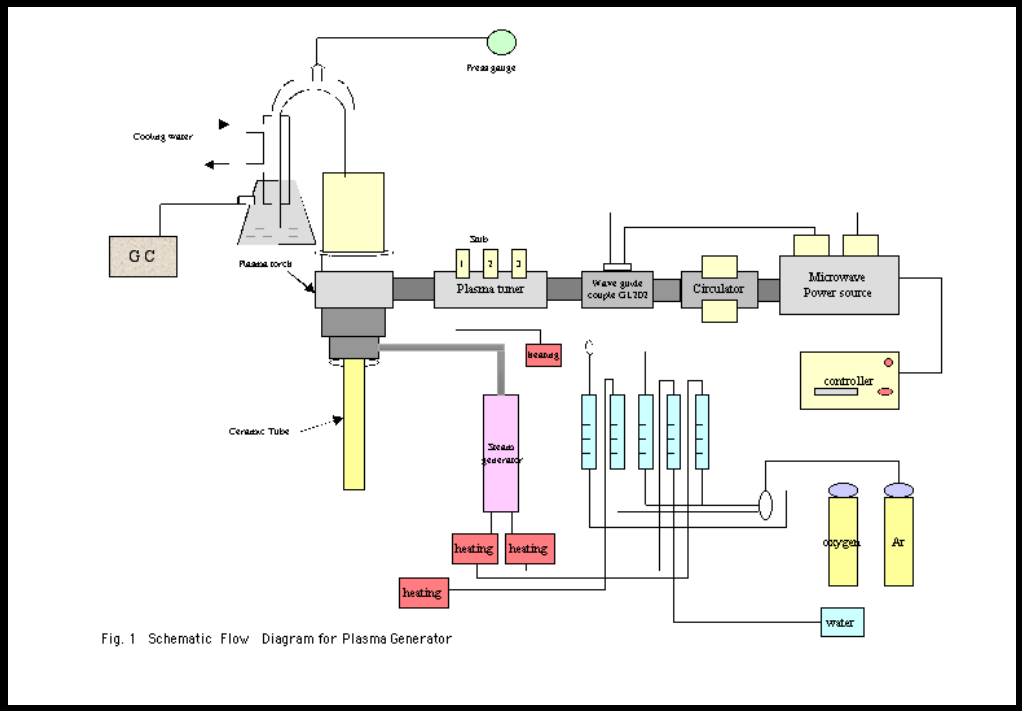
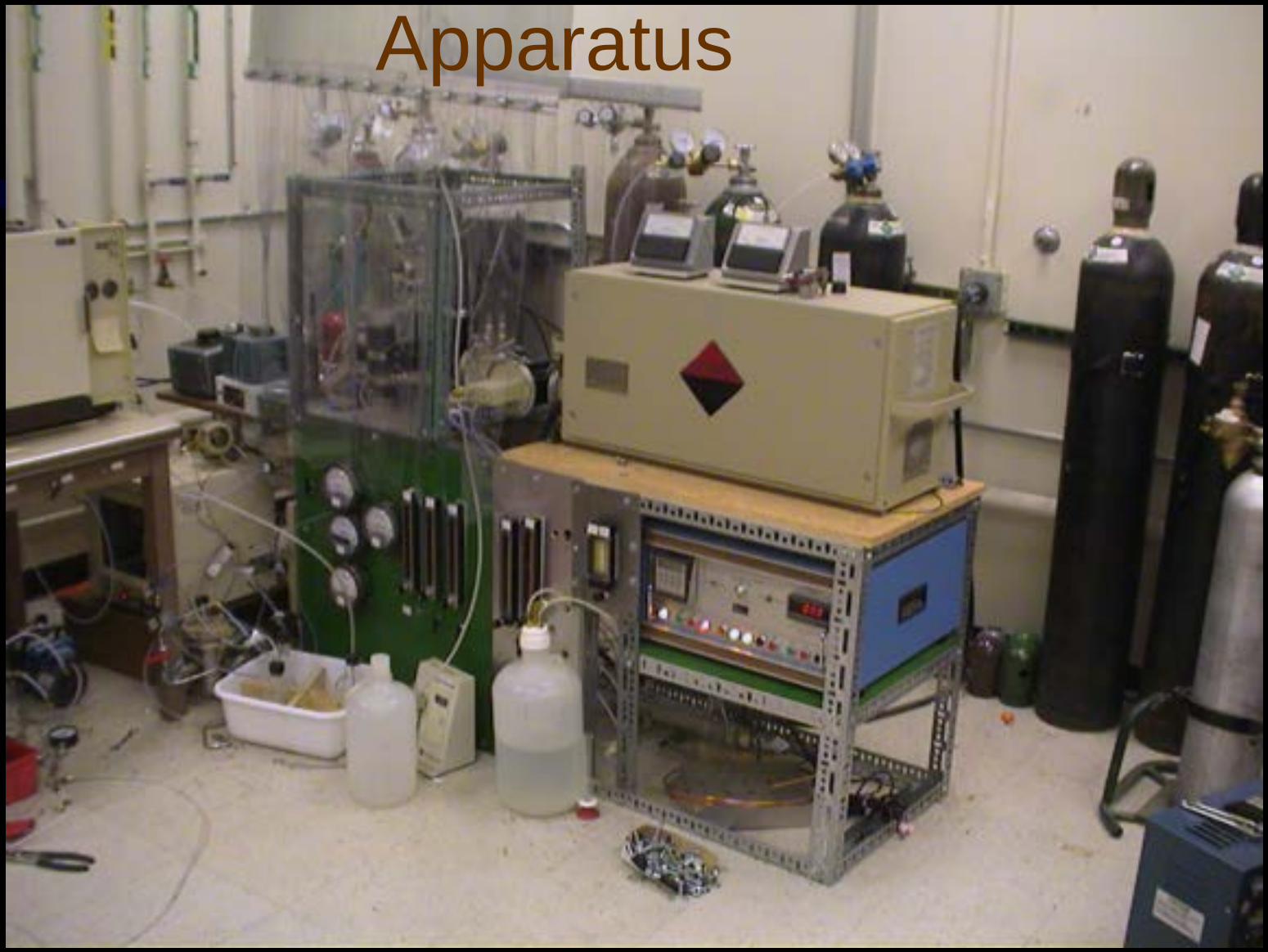


Fig. 1 Schematic Flow Diagram for Plasma Generator

Apparatus



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Plasma torch and tuners

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Experiments

- Argon, oxygen and steam were used to generate plasma
  - Ar was utilized as a basic carrier and reference gas
  - O_2 provided stoichiometric oxidation requirements
  - steam provided a reactive atmosphere containing additional hydrogen
- Steam was generated by a coiled-tubing heater and was carried by Ar gas
- TCE added to flow

Sampling and analysis

- Effluent gas from plasma reactor passed through a coiled water concentrator and an Erlenmeyer flask, in which the most of the steam was condensed. A second back-up trap was used to condense the remaining water vapor
- Gas samples were collected on an adsorbent bed of Carbotrap C.
- A gas sampling loop and switching valve were used to inject gas samples to the GC from a by-pass line exiting the second trap. Liquid samples were also collected from the first and the second traps.
- Reactor effluents were analyzed with an on-line GC equipped with a TCD detector (TCE) and by GC/MS (adsorbent tubes - TCE and other by-products), and a specific ion meter for chloride.

Results

- Conditions
  - The DRE for TCE was evaluated in the microwave system for a series of microwave powers at a condition of 30% steam with an O_2 flow rate of 0.5 lpm and an argon flow rate of 6 lpm.
  - The concentration of TCE in the input flow to the plasma was 1700 ppm.
  - The small amount of O_2 was added to ensure that sufficient O_2 was available in the system to complete the oxidation of TCE.

Destruction efficiency of TCE

- DRE and Cl ion concentration in post plasma gases at different operating powers

Power (W)	DRE (%)	Cl^- (ppm)
200	58	10800
300	99.8	38700
400	100	52000
500	100	56200
600	100	56900

Effect of steam concentration on DRE

- DRE at 600 W of input microwave power and 1700 ppm TCE with varying steam concentrations

Steam fraction of flow (%)	DRE
0	99.78
5	99.9
10	100
20	100
30	100

Thermodynamics

- Dechlorination of these compounds is thermodynamically favored by reaction in a reducing H_2 or water environment. Barat and Bozzelli showed that an overall reaction of the form

  $CCl_4 + 2H_2O = 4HCl + CO_2$

  exhibited large equilibrium constants

T, *K*	K_p
300	3.8×10^{43}
800	7.6×10^{25}

Conclusions

- Steam - microwave system capable of complete destruction of TCE
- Moderate power needed (400 - 600W)
- Presence of steam improves efficiency
- No dioxins or furans formed
- Further studies of kinetics of electron reactions with chlorinated HC’s desirable
- Cheaper, half wave rectified system possible