

Design study for the destruction of trichloroethene

by

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Abstract

The research documented in this paper is being undertaken by IRIS in collaboration with the CRC for Intelligent Manufacturing Systems and Technologies (IMS&T) and HPM. The project commenced in March 2001 and is expected to be completed in 2004.

The aim of this research is to develop a novel microwave-induced ioniser capable of neutralising industrial pollution. Chemical modelling has been used to aid in the experimental design. It has shown that the treatment of dilute pollutant mixtures is likely to be possible using this method, whereas the treatment of pure pollutant streams is not desirable.

1. Introduction

Many processes in industry cause pollution via the generation of Volatile Organic Compounds (VOCs). Potential deleterious effects of the release of these compounds include: acute (e.g. respiratory and nervous system) and chronic (carcinogenic and mutagenic) health effects, soil and ground-water contamination and ozone depletion (World Health Organisation, 2000).

As awareness of these issues increases, government legislation is continually introduced and upgraded. Therefore industries all over the world are being forced to dramatically reduce or eliminate VOC emissions, or stop production altogether.

The conventional methods used to treat pollutants are carbon adsorption and incineration. Carbon adsorption has significant power requirements and typically only removes 60 – 70 % of the pollutant. Incineration (thermal or catalytic) provides very high removal efficiencies through relatively simple means. It can also treat any pollutant and can cope with varying VOC concentrations and compositions as well as variations in the volume of the stream. However, additional fuel must be added when treating dilute VOC streams, making the process extremely energy intensive. The other major disadvantage of incineration is the formation of more damaging pollutants, such as dioxins and furans.

During the last decade, the potential for non-thermal plasmas to treat dilute VOC streams has been recognised and investigated. This process is similar to incineration in that non-thermal plasmas are capable of very high destruction efficiencies. However, by definition the bulk of a non-thermal plasma is much cooler than the electrons (which are eventually responsible for the VOC destruction). Therefore, the energy can be thought of as targeting the pollutants, resulting in much lower power requirements than in conventional incineration.

Non-thermal plasma processes are not fully understood. Modelling aids the understanding of the phenomenon; therefore modelling data can be used to predict behaviour and so helps with experimental design.

Section 2 of this paper discusses the industrial implications of the project in terms of government regulation as well as industrial application. Section 3 describes the experimental rig and techniques. Section 4 presents and discusses chemical modelling activities undertaken.

2. Industrial Implications

VOCs have a wide range of industrial uses including degreasing. Trichloroethene (TCE) is a common vapour degreasing solvent, and HPM use it to clean small metal parts. It is a very basic process in which the solvent is vaporised and then condenses on the soiled parts and runs off, taking the soil off the parts. Most of the TCE used in processes such as these is released as vapour into the atmosphere. A schematic diagram of the degreasing machine at HPM and the proposed location of the microwave ioniser is given in Figure 2.1.

Global regulation on VOCs, including TCE, is being developed. Most governments from developed nations are still in the stage of identifying which pollutants to regulate, and as yet no concrete regulation is applied to the emission of most pollutants into the atmosphere. However, a cautionary approach to minimise their emissions is generally advised, and some countries are already restricting their usage. Quantitative emission restrictions are likely to be introduced within the next 10 years.

The most common control technology, carbon adsorption, is not capable of cleaning waste streams to the levels that are likely to be required by these new regulations. Non-thermal plasmas are capable of destroying very high levels of pollutants, including TCE. At IRIS we are researching the application of a microwave-induced plasma to the vapour escaping the degreasing machine. The position of the microwave plasma ioniser is shown in Figure 2.1 and a schematic is shown in Figure 2.2.

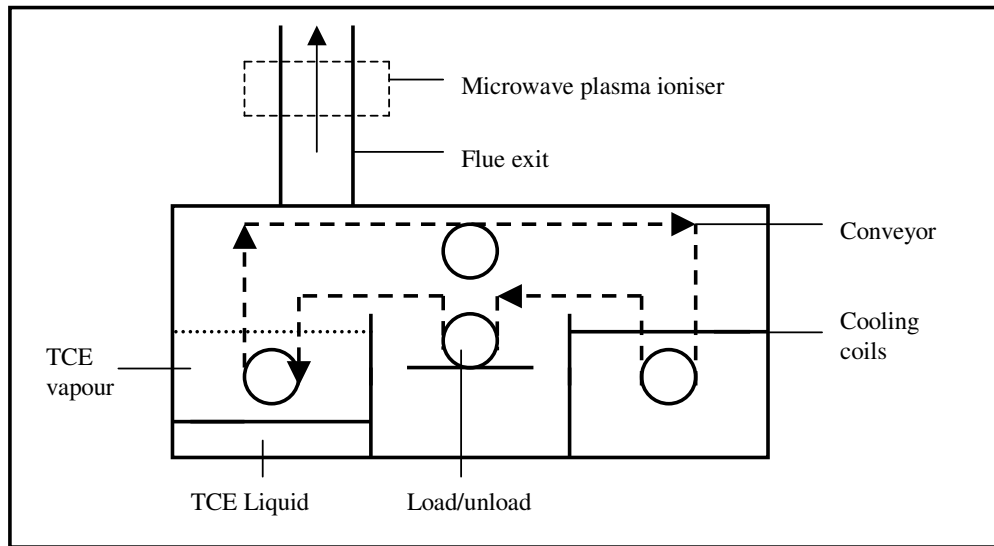


Figure 2.1 - Vapour degreasing machine at HPM

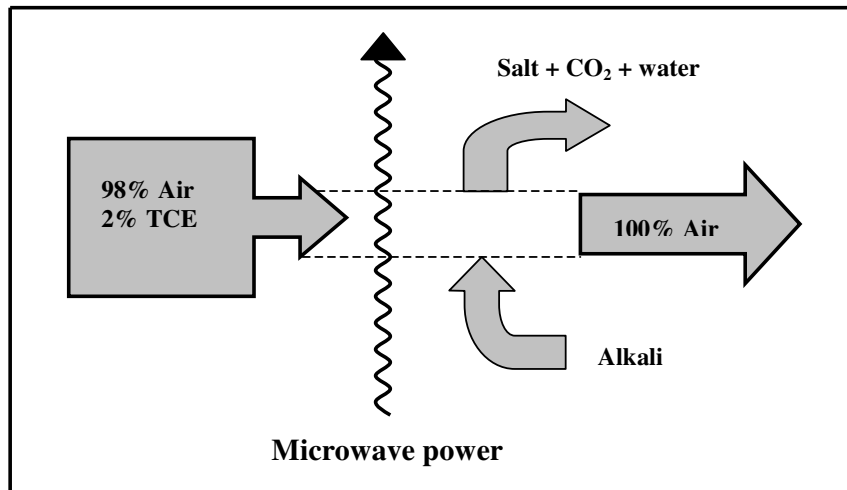


Figure 2.2 - Schematic of microwave plasma ioniser

3. Experimental Rig

3.1 Vapour generator

TCE liquid will be heated to a temperature determined by the desired vapour composition. Air will then be bubbled through the TCE liquid, resulting in a composition-controlled flow of vapour.

3.2 Microwave plasma source

A microwave plasma source that has been developed at IRIS will be used.

3.3 Scrubber

The formation of some acidic gases, such as phosgene, may take place in the plasma. A sodium carbonate scrubber is used to neutralise these pollutants to salt and water.

3.4 Chemical analysis

A gas chromatograph has been acquired for off-gas chemical analysis and is currently being commissioned.

4. Modelling

4.1 Aims of model

4.1.1 Is the process theoretically possible?

The first step is to determine whether the idea is theoretically possible. Although the objective is to convert pollutants into harmless products, the potential for the formation of highly dangerous pollutants such as dioxins and furans during combustion is well-known. Equilibrium modelling with Chemkin enables the identification of conditions that should not allow these products to form. These results are discussed below in Section 4.2.

4.1.2 Is the process economically viable?

It is necessary to show that this process is economically viable in terms of power consumption. Therefore, preliminary power requirements have been predicted using Chemkin's Equil program, as discussed in Section 4.3.

4.1.2 How is the process practically possible?

Kinetic modelling will be required to determine the quench rates (i.e. how quickly the vapour must be cooled after plasma treatment) that will not yield undesirable products. The model must also account for the formation of nitrogen oxides (NO_x), which may also affect the environmental impact of the process.

4.2 Equilibrium Calculations

Figure 4.1 shows the equilibrium products of pure TCE up to 3000K; figure 4.2 shows the equilibrium products of TCE mixed with an equal amount of oxygen over the same temperature range. The products are HCl (hydrogen chloride), Cl (atomic chlorine), C3 (carbon chain of length 3), ClCCCl (dichloroethyne), C₆H₆ (hexachlorobenzene), CO (carbon monoxide), Cl₂ (chlorine gas), CO₂ (carbon dioxide), CCl₄ (carbon tetrachloride) and Cl₂CO (phosgene).

Figure 4.1 clearly shows that the pyrolysis of pure TCE below 2000K would yield hexachlorobenzene. This is a precursor to extremely potent aromatic pollutants such as dioxins and furans. Dichloroethyne is also a possible undesirable product above 1500K. These modelling results suggest that the pyrolysis of pure TCE would yield products that were more harmful than TCE alone.

Figure 4.2 (equilibrium for a TCE /oxygen mixture) indicates that while some undesirable products (i.e. carbon tetrachloride and phosgene) are formed at low temperatures, only carbon monoxide, chlorine ions, hydrogen chloride and chlorine gas are formed above 1000°C. These results indicate that high temperature treatment of TCE with air may be possible.

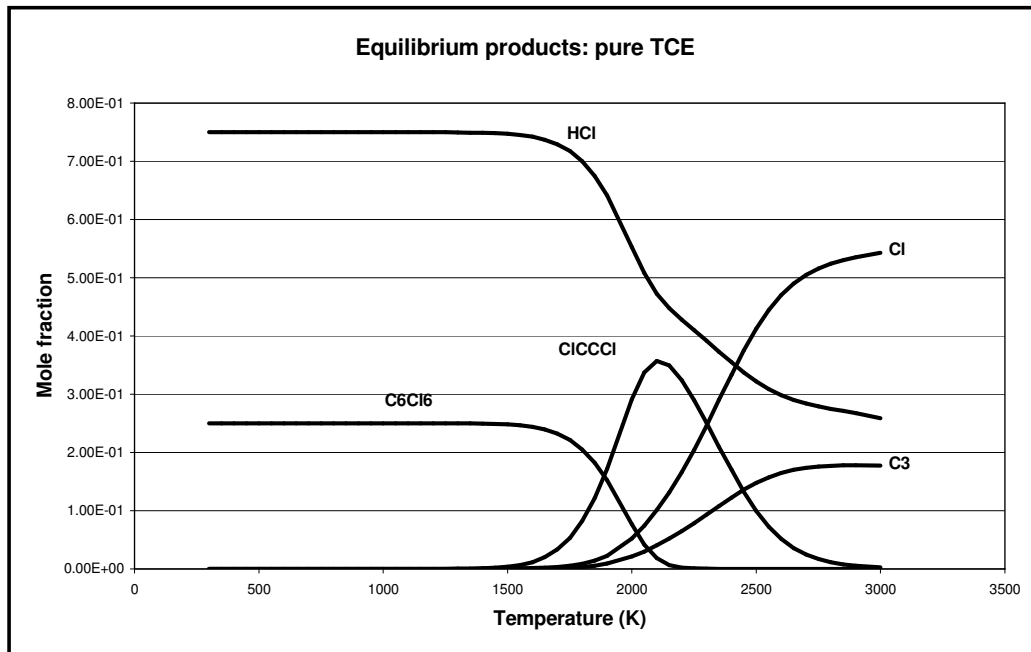


Figure 4.1 – Equilibrium products of pure TCE

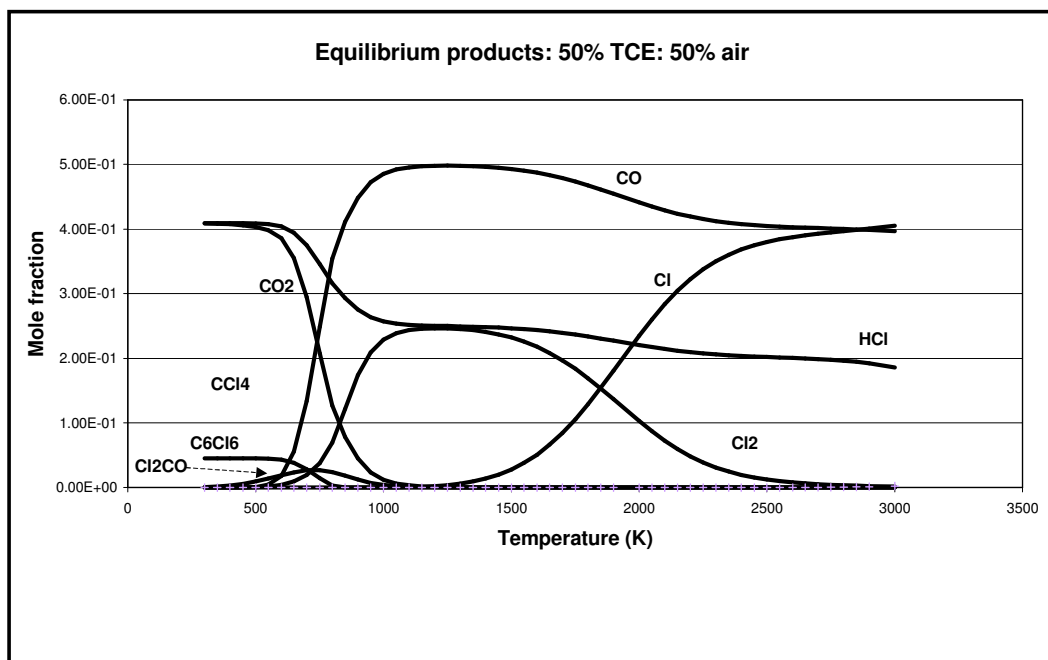


Figure 4.2 – Equilibrium products of a mixture of equal amounts of TCE and air

4.3 Preliminary determination of power requirements

Previous calculations have assumed a mixture of pure air and TCE. However, when considering the heating requirements, the effect of the presence of nitrogen in air when heating will have to be considered. Equilibrium calculations suggest that for a flow rate of 1 l/min, which is comparable with the exhaust flow rate from the HPM degreasing machine, the power requirements would be less than 2 kW. This compares favorably with energy requirements of existing control techniques and other non-thermal plasma sources.

4. Conclusion

This research has investigated the viability of using non-thermal plasma to control trichloroethene vapour emission. Equilibrium modelling has suggested that the dissociation of pure trichloroethene would lead to the production of more potent pollutants such as hexachlorobenzene. However, the addition of oxygen or water to the trichloroethene vapour is likely to enable its dissociation into benign products. Equilibrium modelling has also indicated that the power required in this process is acceptable. Kinetic modelling is now required to determine the required quench rates. The information gained from this modelling will be used to optimise the design and operation of the experimental test rig.