FROM LAB TO REALITY,
PLASMA ENGINEERING FOR POLLUTION CONTROL

S. Hall
AEA Technology plc

INTRODUCTION

AEA Technology has engineered laboratory scale non-thermal plasma technologies into commercially successful systems and processes which are the subject of extensive patents worldwide..For example, systems have been developed for the sterilisation of medical equipment and the removal of volatile organics in the pharmaceutical industry. This paper presents a series of case studies which demonstrate the importance of applications engineering and understanding product requirements in the development of laboratory scale science into plasma-based products.

In the laboratory almost any plasma generating technique can be used to demonstrate the effectiveness or otherwise of a proposed process. However, when attempts are made to scale up and engineer a product to a specification it becomes clear that the plasma generation technique and the associated hardware are key factors in arriving at a commercially viable solution.

Examples of how the product specification influences the choice of the plasma generation technique are illustrated in the following case studies.

INCINERATOR OFF-GAS TREATMENT

Product specification

Figure 1.1 illustrates the client's product specification for incinerator off-gas treatment. The overriding specification requirements are for a rugged system capable of reducing dioxins and furans to <0.1 ng/m 3 (ITEQ) under high gas throug-hput and low pressure drop conditions. These process requirements, which force the downselection of the plasma generation method, are inherent properties of a wire to cylinder corona reactor design. Issues associated with the complexity and size of corona power supply technology (especially in pulsed mode) are minimised in this ground based environment which already employs high voltage electrostatic precipitation.

Incinerator off-gas treatment

Product specification

- Integrated aftertreatment technology designed to maximise process heat recovery potential
- Modular construction (> 1000 m^3/hr per module)
- Reduce raw dioxin and furan concentrations < 0.1 ng/m^3 (ITEQ)
- NOx, SOx and VOC removal capability
- Power requirement < 15 W hrs/Nm^3
- Continuous operation between incinerator maintenance shutdowns
- Economic constraints – proprietary information

Figure 1.1 © AEA Technology plc

Scaling up issues

Initial trials were performed by applying a short-pulse of high voltage to the inner wire electrode of a wire to cylinder geometry reactor, resulting in the formation of small streamers of ionised gas which propagate towards the outer earth electrode. The electrons and ions in these streamers, and free radicals which are formed, process the gas stream. The stability and efficiency of the pulsed corona system is achieved by short high voltage pulses having rapid rise time at high frequency.

The initial laboratory reactor had an inner electrode wire with a diameter of 0.5 mm and an outer electrode cylinder with a 50 mm diameter and length of 100 mm. An immediate challenge was the accurate centering of the wire, as misaligned electrodes had a tendency to arc before peak generation was achieved thus absorbing power and reducing process efficiency.

Pilot scale prototype

The product specification demands high gas throughput with low pressure drop. The impact of scaling the corona reactor to meet these requirements introduces a wide range of design considerations.

Scaling the outer electrode diameter increases the distance between electrodes, resulting in higher operating voltages which raise further issues such as safety and electrical insulation. Non-uniform plasma distribution between electrodes is of concern. In order to ensure efficient energy transfer it is important that the reactor and power supply are considered in combination.

These considerations have resulted in the development of a patented 7.5 liter volume geometry system. A bank of four such reactors has been successfully demonstrated at a domestic waste incinerator in the UK. Confirmation of the corona reactor's performance during this demonstration is illustrated in Figure 1.2. This shows typical reactor performance data. The data was recorded just after a truckload of hospital waste had been delivered for incineration. The data shows a background VOC emissions spike from the burn. Note the reduction in VOC when the plasma is applied at t = 4 minutes and t = 20 minutes.

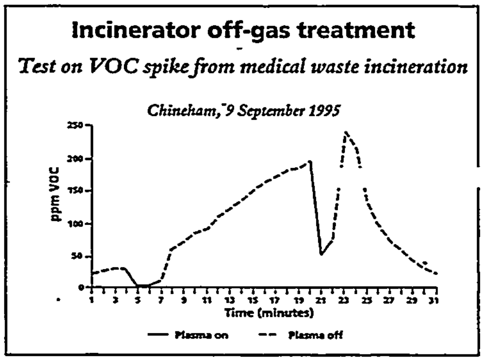

Incinerator off-gas treatment
Test on VOC spike from medical waste incineration
Chineham, 9 September 1995

Figure 1.2 © AEA Technology plc

Final product modular design

Further scaling up of both the corona reactors and power supply was necessary to achieve the requirements laid down in the product specification. Taking into consideration firstly, the product specification and secondly, the valuable lessons learnt under real world conditions by operating the pilot scale system at the incinerator (in particular, differential thermal expansion and the corrosive nature of incinerator off gas), a 1000 nm³/h modular system has been developed. Figure 1.3 shows the AEA Technology corona system undergoing trials in the UK. The system met the demands laid down in the product specification. Figure 1.4 illustrates typical experimental data, confirming the reactor's performance in meeting the required emissions target.

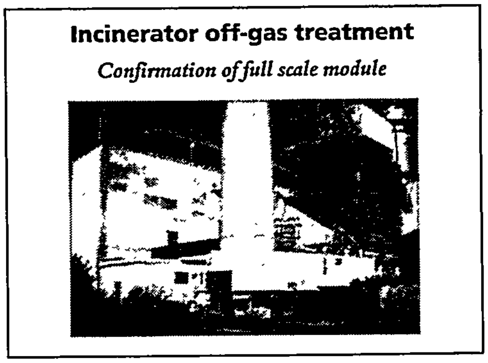

Incinerator off-gas treatment
Confirmation of full scale module

Figure 1.3 © AEA Technology plc

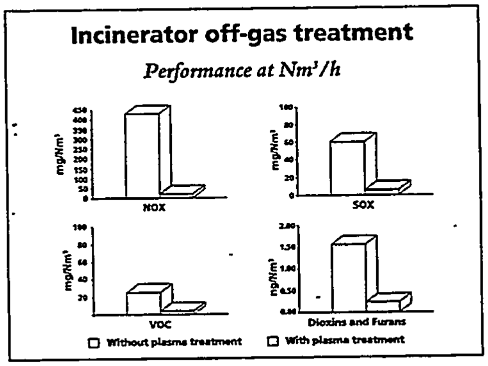

Incinerator off-gas treatment
Performance at Nm³/h

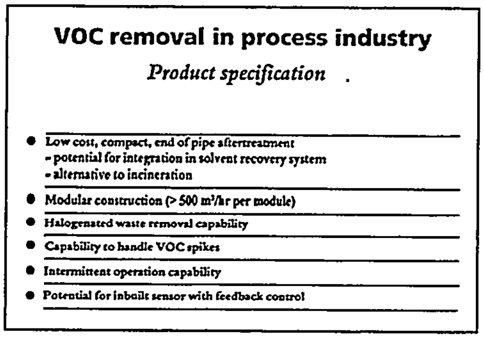
Figure 1.4 © AEA Technology plc

VOC REMOVAL IN PROCESS INDUSTRY

Product specification

The second case study examined is that of microwave plasma technology for application to VOC removal in the process industry. Figure 2.1 illustrates the product specification set out by the customer.

In this instance the client was looking for an economic and practical alternative to incineration, which could be integrated into the existing solvent management system. Cost is the determining factor governing the engineered solution. Utilising off the-shelf 2.45 GHz microwave magnetron technology provides both a cost effective and efficient means of generating a plasma. The 2.45 GHz magnetron is a continuous wave generator. It's disadvantage is a tendency to form a thermal plasma and this represented a significant engineering challenge.



VOC removal in process industry

Product specification

- Low cost, compact, end of pipe aftertreatment
  - potential for integration in solvent recovery system
  - alternative to incineration
- Modular construction (> 500 m^3/hr per module)
- Halogenated waste removal capability
- Capability to handle VOC spikes
- Intermittent operation capability
- Potential for inbuilt sensor with feedback control

Figure 2.1 © AEA Technology plc

Scale up issues

The tendency to form a thermal plasma can be overcome with high gas flows. However, it is generally difficult to initiate and stabilise atmospheric discharges at high gas flows utilising microwave technology. The challenge was to design and develop a reactor capable of both initiating and producing a stable non-thermal discharge. The reactor electrode geometry is illustrated in figure 2.2A. The plasma is generated using field enhancing electrodes each of which has a radial gas passage. An annular gap between the electrodes serves to generate the plasma. This gas processing region is a hostile environment in which corrosive gases form rapid wear conditions and where temperatures under low flows can rise to in excess of 1500 K. Meeting the demands of the final product specification also represents a significant metallurgical challenge, and a wide range of transitional materials have been evaluated to improve the operational lifetime of the electrode.

Pilot scale prototype

The engineering challenge in scaling up the microwave reactors is to satisfy the conflicting requirements of higher gas throughput whilst achieving a stable plasma. The development of the patented microwave reactor illustrated in Figure 2.3 utilises a PTFE cassette which forces the process gas to rotate around the electrode knife edges, as shown in figure 2.2A. This helps to achieve increased residence time and plasma stability. It is essential that the cassette is manufactured from a material that is microwave transparent, such as PTFE. However, the introduction of a PTFE cassette distorts the microwave wave front resulting in a less than optimum transfer of power. The engineering solution to overcome this inherent problem was to devel-op and incorporate a low cost wave-guide transformer tuning mechanism into the design of the reactor. Figure 2.4 shows the system's ability to convert hydrocarbons,such as clichloromethane, into soluble hydrogen halide. The soluble gas can then be processed using existing solvent management recovery systems.

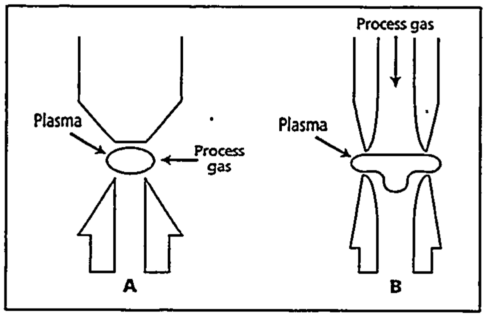
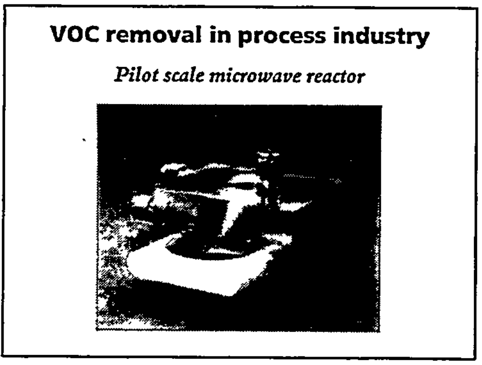


Figure 2.2A and B © AEA Technology plc

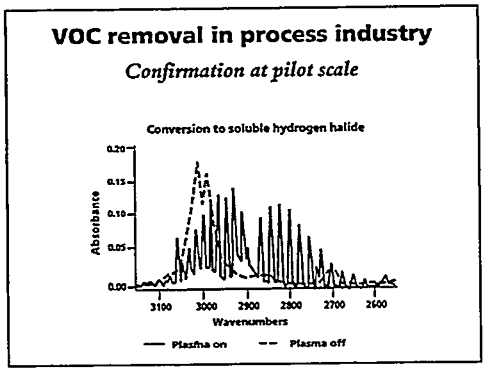


VOC removal in process industry

Pilot scale microwave reactor

Figure 2.3 © AEA Technology plc

The final product specification requires a cost effective end product, capable of processing high gas throughput with low pressure drop. In order to achieve the latter it was necessary to develop the axial flow electrode geometry illustrated in figure 2.2B. Process gas flows of 1000 slm through a single reactor have been achieved in this way.



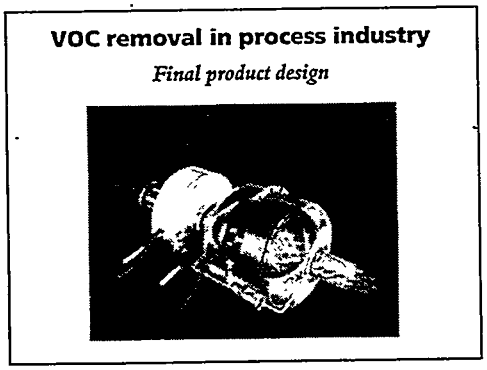
VOC removal in process industry

Confirmation at pilot scale

Figure 2.4 © AEA Technology plc

Final product design

To achieve efficient energy distribution at high gas flows electrode arrays were considered, utilising a single magnetron. However, the cost driver dictated the development of a close coupled magnetron assembly. Figure 2.5 illustrates the final patented product design, which meets the product specification.



VOC removal in process industry

Final product design

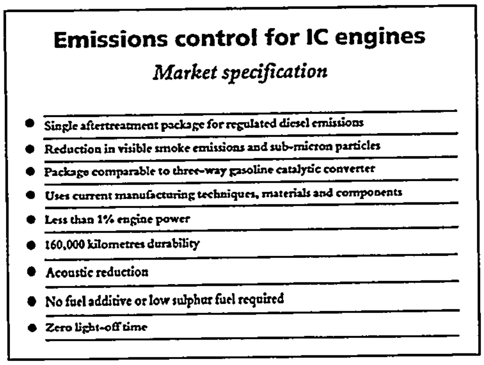
Figure 2.5 © AEA Technology plc

EMISSIONS CONTROL FOR IC ENGINES

Market specification

The third case study is surface discharge plasma technology applied to automotive exhaust aftertreatment. Health issues and public opinion are forcing legislators to introduce tighter emissions standards. The stringent legislation earmarked for the new millennium both in North America and Europe requires an effective, affordable solution in a single aftertreatment package to meet the specification set out in figure 3.1.

AEA Technology is addressing this requirement with the development of the ELECTROCAT™ Clean Emissions System, a patented plasma catalyst which has the capability of simultaneous particulate removal and NO. reduction. Again, the demands for cost, durability and efficiency forced the downselection of the plasma generation technique, which in this case requires the production of the plasma without elaborate expensive power supplies.



Emissions control for IC engines

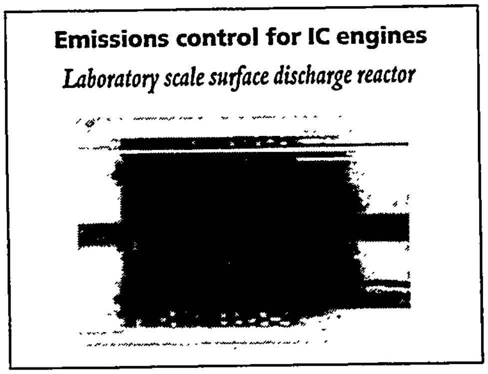
Market specification

- Single aftertreatment package for regulated diesel emissions
- Reduction in visible smoke emissions and sub-micron particles
- Package comparable to three-way gasoline catalytic converter
- Uses current manufacturing techniques, materials and components
- Less than 1% engine power
- 160,000 kilometres durability
- Acoustic reduction
- No fuel additive or low sulphur fuel required
- Zero light-off time

Figure 3.1 © AEA Technology plc

Confirmation at lab scale

The original lab scale device is shown in figure 3.2. Early trials of this device were carried out at Southwest Research Institute (SwRI), processing diesel exhaust from Dodge and Toyota diesel pickup trucks. The glass-tube reactor used in these trials consisted of an A.C. voltage applied across ceramic packing material. The material can be modified to assist catalytic activity to further enhance the performance of the discharge reactor.



Emissions control for IC engines

Laboratory scale surface discharge reactor

Figure 3.2 © AEA Technology plc

Figure 3.3 illustrates typical test data recorded at SwRI and confirms the simultaneous particulate removal and NOx reduction efficiencies (of up to 90% and 70% respectively) which were achieved with the lab scale device.

Full scale prototype

AEA Technology has continued to develop and

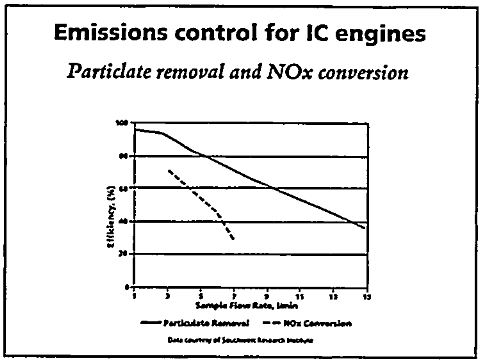


Figure 3.3 © AEA Technology plc

engineer the ELECTROCAT™ since these early trials, and has designed and manufactured full scale plasma reactor systems, the designs of which are proprietary and subject to patent filings. Testing of these prototypes has provided verification of the SwRI laboratory scale data at full scale. ELECTROCAT™'s performance data base has been extended to include European regulatory drive cycles (ESE+EDUC.) modified with Year 2000 test protocol, and confirmation of the removal of ultra-fine sub-micron particulate, as illustrated in Figure 3.4.

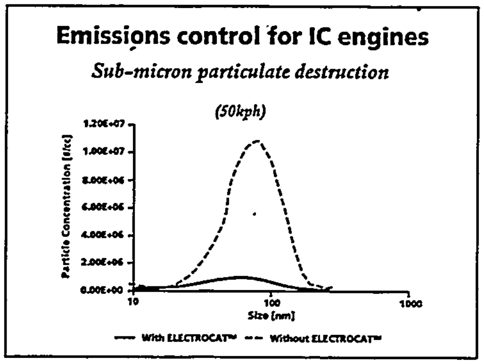


Figure 3.4 © AEA Technology plc

Final product design

Further development programmes and trials are now focused on production engineering the device to meet the market specification. Figure 3.5 illustrates one of the first engineered prototypes, which are scheduled to undergo tests in 1998.

Conclusion

An understanding of plasma technology and the final product requirements are fundamental to developing a successful product. No one plasma generation technique offers a universal panacea for emissions control, and, irrespective of what can be demonstrated in the laboratory, it is the applications engineering and system integration of the right plasma technology which will determine the successful product. By understanding and following these principles, a correctly engineered and integrated plasma technology can provide effective and commercially desirable solutions to meet a range of emissions targets.

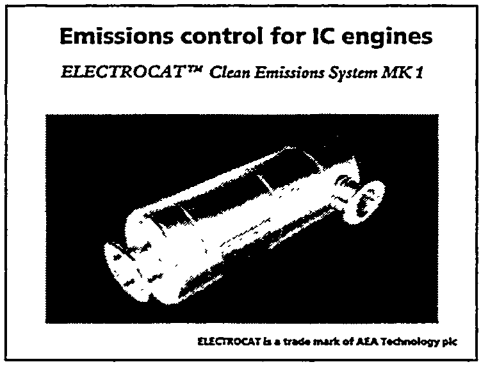


Figure 3.5 © AEA Technology plc

Background Sources

1. Process Engineering, Miller House Publishing, London, March 1997.

2. The Engineer, Miller House Publishing, London, 13 March 1997.

3. Semiconductor International, Cahners International Publishing Company, October 1997.

4. Industrial Environmental Management, Faversham House Group, July 1997.

5. Shawcross, J. T., PhD thesis entitled *The Application of Non-thermal Plasmas to the After-treatment of Diesel Engine Exhaust*, September 1996, and references therein.

6. Penetrante B.M, Schultheis S.E., *Non-thermal plasma* techniques for pollution control, Springer-Verlag, 1993.

Acknowledgments and Thanks

The author wishes to thank Bob Fanick and Bruce Bykowski of the Southwest Research Institute, Texas. The author also thanks Dave Raybone, Fiona Winterbottom, and all his colleagues involved in the development of plasma processing products at AEA Technology.

For further information about plasma processing at AEA Technology or enquiries about copyright and reproduction of any part of this paper, please write to Yvonne Zaslawska, Information Manager, Environmental Technologies, at AEA Technology plc, F4 Culham Science Centre, Abingdon, Oxfordshire OX14 3DB, United Kingdom or e-mail yvonne.zaslawska@aeat.co.uk