Sixth Framework Programme

Horizontal Research Activities involving SMEs
Cooperative Research Projects

(CRAFT)

Publishable Results

Contract number: **COOP-CT-2005-017658**

Project acronym: **MICROCHEM**

Project full title: **A Multipurpose Industrial Chemical Reactor using Tuneable Frequency Microwaves**

Duration: 30 Month (1 February 2006 – 31 July 2008)

Project Co-ordinator: Professor Ahmed Al-Shamma'a
Liverpool John Moores University

Contractors:

No	Type	Name	Country	Short Name
1	RTD	Liverpool John Moores University	UK	LJMU
2	SMEP	Surface Transforms	UK	ST
3	SMEP	Combilift	Ireland	CL
4	SMEP	FELDEC	UK	FD
5	SMEP	Protensive	UK	PR
6	SMEP	Aspen Electronics	UK	AE
7	SMEP	MercaChem	Netherlands	MC
8	OTH	Organon (France)	France	OR
9	RTD	University of Rennes	France	UR1

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1. Objectives summary of the project

The chemical industry is a major contributor to employment, technology and wealth creation in Europe and directly employs 520,000 people. More than 95% of the chemical companies are SMEs employing about 30% of the workforce. To maintain this position, the chemical industry is constantly seeking to increase yields and reduce production times.

Microwaves operating with a frequency of 2.45GHz are able to drastically reduce chemical reactions from hours, under conventional heating, to just minutes and in addition produce more controlled reactions required to create eco-friendly green chemistry. Currently only a laboratory system exists for producing a few cc of chemicals. The project aims to develop multipurpose prototype chemical reactor using microwave chemistry, for the continuous production of bulk chemicals at commercial production rates (kg/hr). This was achieved by combining, for the first time, both MSDR and MCFR technologies and microwave sources having both tuneable frequencies and power in order to optimise the reaction temperature. The availability of a tuneable frequency will allow the microwave process to be optimised at all stages of its reaction to generate maximum product yield whilst reducing the time consuming chemical extraction procedures. In addition, sensors for measuring temperature, power and dielectric properties within the chemical reactor, has been implemented to control the process. It is proposed to use the new system to investigate the production of some important pharmaceuticals having a high commercial added value. The selection of theses chemicals have been requested by the industrial partners. Such experiments have created a wealth of new information, from which have been possible to elucidate the mechanism of how microwave energy is able to substantially speed up these polar chemical reactions. By creating a microwave chemical reactor both the microwave and chemical sectors of industry will benefit by the consolidation of existing employment in the EC and create new jobs by gaining a technology lead over the competitors in the USA, Canada and Japan.

2. MICHROCHEM Objectives

- To specifically develop a multipurpose prototype reactor for the synthesis of bulk quantities (kg/hr) of fine chemicals on a continuous basis by using combined centrifugal and microwave technologies.
- To select the reaction time, microwave power and frequency within the operating range 2 to 26GHz to produce fine chemicals with high yield, low waste and requiring the minimum of product extraction.
- To use solvent free chemistry to avoid waste disposal problems.

- To research self-tuning computer control strategies to optimise the speed and yields of reactions by matching the microwave frequency and power to the variable chemical reaction conditions.
- To achieve a ten fold step change in efficient use of resources (energy, chemicals and solvents).
- To use the reactor to investigate, in depth, four important pharmaceutical reactions. By using the data from these reactions to obtain, for the first time, an explanation of the mechanism of microwave assisted chemistry.

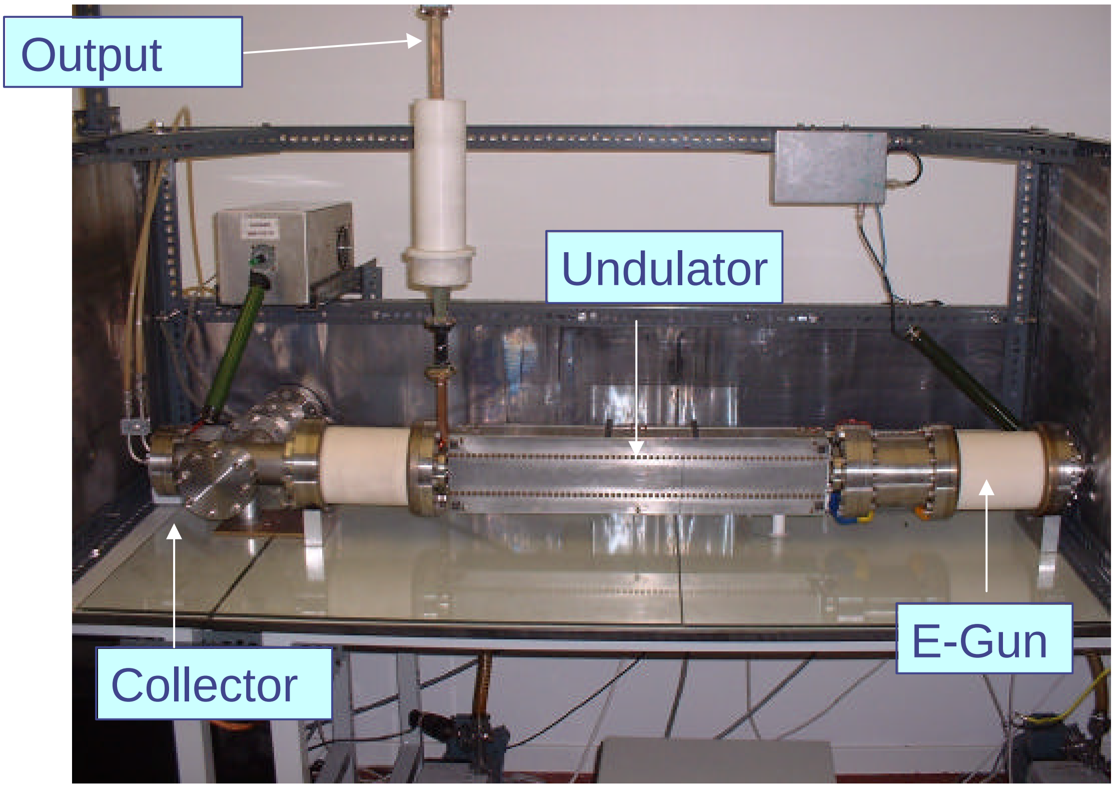
3. Overview of the Project Work Packages

The summary of the project main activities from 1st February 2006 to 31st July 2008 are summarised below:

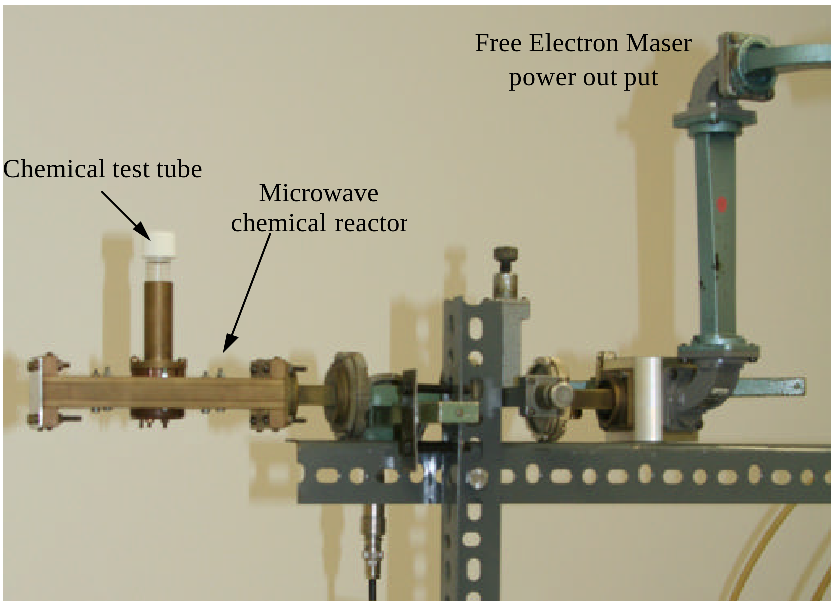
- There are in total seven workpackages to be undertaken (WP1 to WP7).
- WP1 (Design and construction of a continuously operating centrifuge/spinning disc reactor holding up to 100cc of reactants for the MICROCHEM system).
- WP2 (Design and construction of the microwave cavity to operate in the frequency region 2 to 26GHz for the MICROCHEM system).
- WP3 (To establish computer control of the chemical reaction within the MICROCHEM system using multiple sensor information).
- WP4 (To undertake a test chemical reaction (e.g. formation of oxadiazoles).
- WP5 (Use of MICROCHEM for the production of bulk fine chemicals for the pharmaceutical industry by using the four types of reactions).
- WP6 (Process modelling and optimisation of the microwave chemical reaction).
- WP7 (Management and Commercial exploitation).

4. Microchem Achievements

- A chemical microwave reactors operating at 2-26 GHz with various microwave powers have been designed, constructed and tested. The completed Tuneable microwave Free Electron Maser is shown in figure 1 and 2 and Travelling Wave Tube 3.



(a)



(b)

Figure 1: Tuneable Free Electron Maser source operating in both continuous and pulsed mode. (a) Complete system set up. (b) Microwave chemical reactor (8-18 GHz)

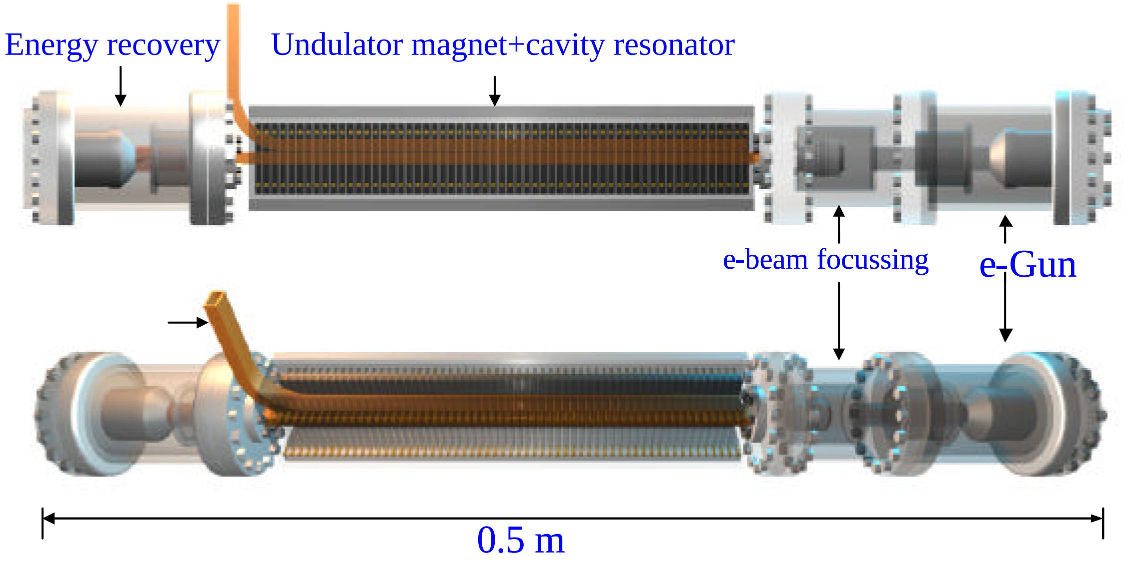


Figure 2: The potential industrial tuneable FEM suitable for various pharmaceutical applications

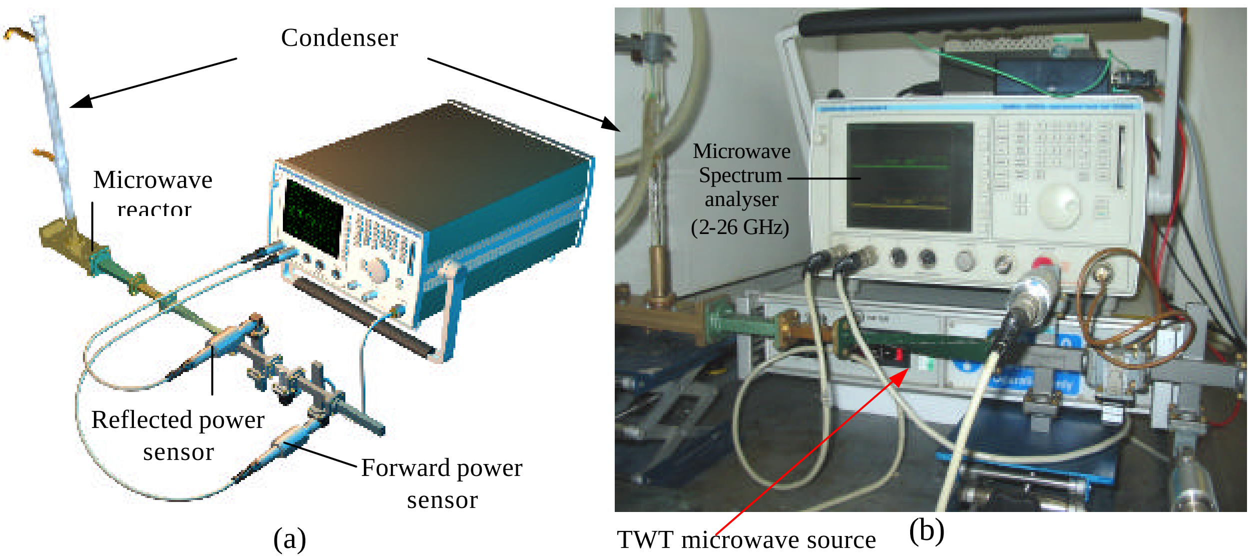


Figure 3: The microwave chemical reactor operating at 4-26 GHz. (a) schematic diagram (b) in operation using TWT microwave source and spectrum analyser

- A comprehensive theoretical and electromagnetic modelling for the multipurpose microwave chemical reactors has been completed for investigating the microwave thermal and non-thermal effects on the chemical physical properties before, during and after interacting with the microwave energy. The results achieved have shown that most of the chemical reactions respond differently at higher frequencies. Various chemical reactions have been studies conventional and non conventional a higher yield has been achieved at higher frequencies using fraction of the power used in the conventional microwave synthetic system. This is a major breakthrough in terms of efficiency, energy saving and environment.

- This is the first time a novel design of microwave spinning disc reactor (MSDR), see figure 4, operating at 2.45GHz has been designed and constructed to produce green solvents and large scale of pharmaceutical products at very short time in comparison to current microwave synthetic devices.

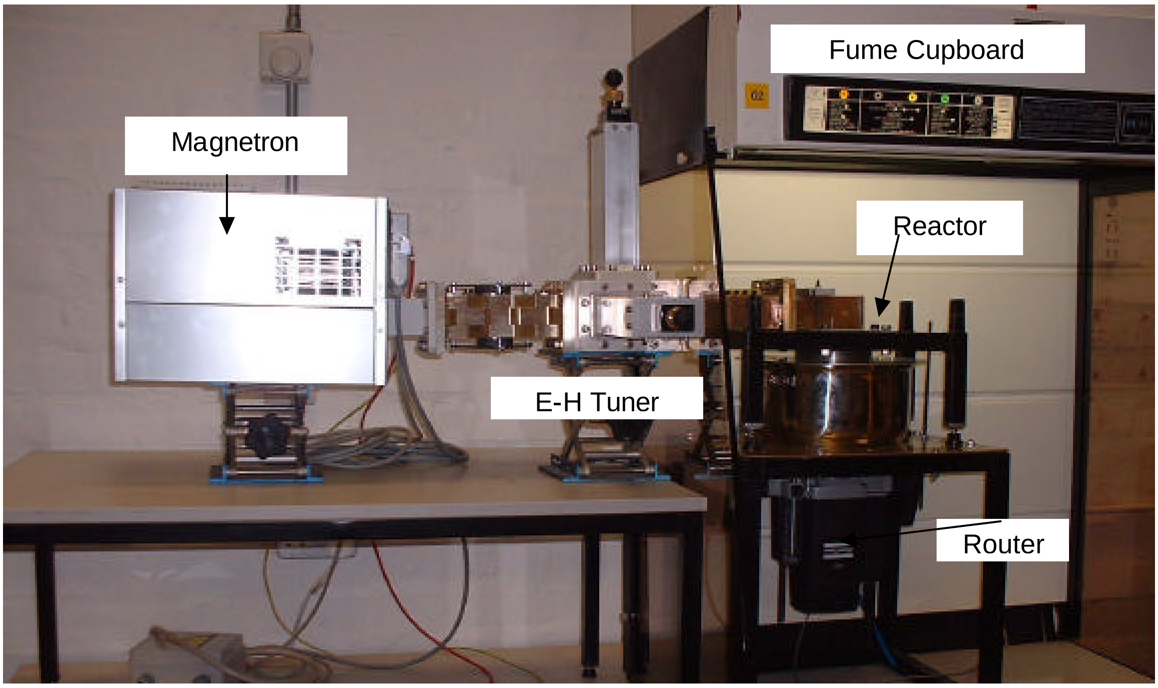


Figure 4: The complete industrial microwave MSDR system operating upto 2 kW.

- Other microwave reactors was designed, constructed and tested during this project including a true microwave continuous flow reactor (MCFR). Flow Chemistry is a technique, which can be used for reaction optimisation, synthesis and scale up of chemical reactions. Due to the size of the reactors excellent heat and mass transfer is achieved which lead to: Higher reaction yields vs. traditional chemistry systems, Better selectivity, Scalability is achieved by simply pumping continuously the reagents, Reactions performed in such a small volume are intrinsically safer than traditional synthesis methods, especially when handling hazardous reagents and highly exothermic reactions, e.g. nitrations, oxidations, etc and allows the chemist to optimise reaction conditions and use them to produce the required amount without a need to re-optimise.
- Furthermore, the use of the microwave flow reactor in speeding up the transestrification reaction in the production of Biodiesel. The use of this system has lead the reaction of oil and solvent (methanol or ethanol) to be completed in minutes rather than in hours if

compared like for like with the conventional thermal transestrifcation reaction. Also the less percentage ratio use of solvent to oil and percentage volume of catalyst was reduced drastically using the microwave flow reactor.

- For any chemical reactions to be carried out in the MSDR and MCFR systems with optimised parameters such as frequency, power, temperature etc, a computer control using multiple sensors was designed, constructed and currently under testing for industrial exploitation. Standalone software has been designed, written and implemented based upon the industrial partners' requirements. A number of features are included in the software, such as the display of; forward/reverse microwave power, temperature, frequency, microwave power setup, operated frequency setup, online temperature setup, temperature/power graphing and data logging.
- The control process is carried out using a PID controller and LabView, see figure 5, and was used as a means of keeping a constant microwave cavity power defined by the user in the software system. Constant on line real time monitoring and control is required of the power due to the changes of the dielectric properties of the chemical samples during the heating process in order to sustain the optimum conditions for such chemical reaction.

Figure 5: Front Panel for the SDR control VI

- **One of the major achievements is the Pioneering Break Through Employing the MSDR and MCFR for the Production of Ionic Liquids**. The pharmaceutical industry is undoubtedly facing a series of production-based challenges. However, whilst many of these challenges are related to the nature of this particular industry and it's inherent current business models, there is also an urgent need for new science to bring forward innovative and effective drugs and therapies. The classic strategies currently being followed are reaching a saturation point in which it is getting more difficult to realise effective, acceptable new chemical entities.

  Less than one tenth (1/10th) of the drugs in clinical trials make it to the market, causing the development companies to incur huge losses, and reducing the availability of efficient pharmaceuticals in the market for the people who need them. In the present scenario the number of new drugs approved annually continues to decay, the novel active compounds now proposed tend to have more and more problems in matching all the desired requirements of solubility, bio availability, stability, etc.

  Approximately a decade ago, mainly due to the tuneable properties and the extremely low volatility of many ionic liquids, these substances started to catch the attention of the academic and industrial communities as potential alternative solvents (with some use within the field of the pharmaceutical industry). Some years later, a notable interest in materials applications of these liquid salts also arose, thus focusing attention not only on the physical properties of the ionic liquids, but on their chemical properties, as well. But it is only recently that there has been a major emphasis placed on ionic liquids as bearers of desired biological activity (even though ions known to be biologically active have been used in ionic liquids for quite some time).

  The main technological applications for the ILs:

  - Thermal fluids
  - Novel media for various reactions (Hydrogenation, Hydroformulation, Epoxidation, Diel-Alder reaction, Free-radical polymerisation, Heek reaction, Suzuki coupling reaction)
  - High temp/low temp lubricates
  - Electrochemical cells and devices (Li metal and Li-ion batteries, Double layer capacitors, Electrochromic displays (OLEDs), Sensors, Fuel cell membranes)
  - Hydraulic fluids

Currently, the cost of producing 10ml of ILs is approximately €100 at 2008 prices. It currently takes at least 24 hours to produce 10ml of ILs in conventional heating and 5-6 hours in current industrial microwave synthetic devices such as CEM and parabola. It was demonstrated during the MICROCHEM project that in just a few minutes 200ml can be produced through the Microwave Spinning Disc and Flow reactors optimised process, see figure 6. This is indeed, a pioneering scientific breakthrough.

Figure 6: The production of ILs using MSDR and MCFR

- Thorough out the period of the MICROCHEM project, we have published over 40 scientific publications in journals and national and international conferences.
- Various awards have been achieved in the international conferences for best papers and research activities.
- Two spin-off companies have been established as an outcome from the MICROCHEM project.