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TITLE: EUROPEAN CONCERTED ACTION ON PROCESS TOMOGRAPHY FOR IMPROVING THE DESIGN AND OPERATION OF INDUSTRIAL PROCESSES

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TU Delft
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City University
Birmingham University
Sheffield University and Health Authority
Sheffield Hallam University
Leeds University
University of York
University of Surrey
University of Bergen
University of Karlsruhe
University Hospital, Lund
University of Aveiro
University Polytechnic of Catalunya
Inserm, Toulouse

B N F L
Unilever
British Coal
ICI
SIMS
MIRO
BP
Schlumberger

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# Coordinated Activity on Process Tomography for. Improving the Design and Operation of Industrial Processes: The European Concerted Action on Process Tomography (ECAPT)

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## 1. Abstract

The main objective of the concerted action was to improve the design and operation of industrial process plants by topographically imaging the distribution of materials in process vessels and pipelines. The 4 ECAPT technical meetings have resulted in the forging of technical relationships between academic groups and in focusing and prioritizing process application needs under the guidance of industrial participants. Output from the programme has been disseminated by means of 4 books, 4 newsletters, over 200 technical papers and an electronic (Internet) database service.

## 2. Introduction

The European Concerted Action on Process Tomography (ECA PT) aimed to bring together a diverse range of disciplines to allow an integrated approach to the speeding of development and industrial exploitation of tomographic technology. Tomographic derived data may be used for:-

i. process model verification (to design improved equipment)
ii. process operation and control (internal measurements by tomography will give better information on process behaviour than will external measurements)
iii. multi-component flow measurement (eg oil/gas mixtures, pneumatic conveyors)

From small beginnings the ECAPT meetings held in Manchester (1992), Karlsruhe (1993), Oporto (1994) and Bergen (1995) grew to represent the activities of several, hundred researchers and dozens of industrial collaborators encompassing over 15 different sensing principles. By the end of the programme this had begun to have a radical impact on the exploitation of tomographic methods in manufacturing industry as evidenced by the marked demand for industrial' field trials, growing industrial membership and development of innovative integrated translational multidisciplinary research projects.

## 3. Technical description

### 3.1 Objectives of the Project

The objectives of the project were to persue the following activities and produce the appropriate deliverables.

3.11 Technical Workshops to Foster Collaborative Research and Exchange

The primary objective of the programme was to.. have. .an. .annual. meeting .of. technical workshops for workers from European industrial research institutes and universities, in order to: -

a) monitor and encourage the success of their projects in Process Tomography
b) facilitate transferring tomographic technology from medicine to process plants
c) develop a longer term strategy for ensuring the success of process tomography in improving industrial productivity and safety

The first meeting was held in Manchester (UK) from 26 to 28 March 1992. This was attended by 64 delegates representing 10 countries with 10 industrial participants and 54 academic researchers". The total number of "participants was limited partly because of limitations imposed by the conference venue but also to facilitate interchange of ideas. The meeting was based on the theme "A Strategy for Industrial Exploitation" and sought to identify the current status of the technology and the steps needed to meet the perceived industrial needs. Attendance was by invitation on the following basis:-

i. For active research groups - on the basis of acceptance of a research paper
ii. For active industrial research organisations - on the basis of an accepted research paper or presentation of a poster
iii. For manufacturing or other industrial concerns not yet active in the area but see potential applications of the technology - on the basis of presentation of a poster and/or verbal participation in the panel discussions.

In addition all groups attending were required to complete a status report detailing the level of activity in process tomography and research goals for the next five years.

The second technical meeting was held at the University of Karlsruhe, (Germany) from 25 to 27 March 1993. This was attended by 90 delegates representing 11 countries with 17 industrial participants and 73 academic researchers. The meeting was again based on the theme "A Strategy for Industrial Exploitation" and sought to identify how the technology had moved forward in the year since the meeting at Manchester and the steps still required to meet the perceived industrial needs. ECAPT '93 was organised with sessions which enabled the common technologies involved in tomographic technology (particularly image reconstruction" techniques and computational methods) to be presented during a single session. This enabled useful information exchange and advancement of a common approach across the community. Attendance was by invitation on the same basis as in 1992. Requests for attendance (186) vastly exceeded the number of funded places available (80). The meeting took the form of workshops, laboratory visits and presentations anti poster discussion periods. The presentations including a special "applications" day where key application case studies were presented and to which additional representatives of' process engineering and related industries were invited.

The third technical meeting was held at the Hotel Meridien, Oporto, (Portugal) from 24 to 26 March 1994. This was attended by 98 delegates representing .9 countries from 22 industrial and 31 academic groups. This year demand for places at the technical meeting had grown to the point where it was no longer possible to fund all those wishing to attend. For the first time places were made available on payment of a fee covering hotel and registration costs. '[n order to made funding available for the greatest number of places travel grants were not given this year.

In order to maintain the high overall standard of papers strict refereeing was introduced this year for the first time and allocation of the limited number of. funded places to groups was made conditional on the. acceptance of a paper by the management sub-committee set up to oversee the process. This was in addition to the completion of a status report as required in previous years. To allow sufficient time for this rigorous refereeing the call for papers was sent out much earlier. The papers and keynote reviews to be presented at the meeting were distributed to delegates 2 weeks before the meeting so that they had time to read and consider the material to be presented. This was much appreciated and was felt to contribute to the quality of the discussion and interchange of id eas. Keynote reviews were introduced for the first time at this meeting.

The fourth technical meeting was held at the Suitell Edvard Grieg in Bergen, (Norway), which was attended by 107 delegates representing 10 countries from 14 industrial and 34 academic groups. Places were allocated as the previous year on the basis of the acceptance of one or more refereed papers and the completion of a status report. Demand for places at the technical meetings had continued to grow beyond the point where it was possible to fund all those wishing to attend. Additional places were made available to academic delegates on payment of a fee covering hotel and registration costs, while all industrial delegates were asked to pay a conference fee reflecting the true costs of attendance. In order to make funding available for the greatest number of p] aces travel grants were only given to keynote speakers.

**SUMMARY OF ATTENDANCE AT THE TECHNICAL WORKSHOPS**

| | ECAPT '92 | ECAPT '93 | ECAPT '94[1] | ECAPT '95[1] |
|---|---|---|---|---|
| COUNTRIES | 10 | 11 | 9 | 10 |
| Total number of groups represented | 29 | '41 | '53 | 48 |
| Research Groups | 21 | 28 | 31 | 34 |
| Industrial Groups | 8 | 13 | 22 | 14[2] |
| Total number of delegates | 64 | 90 | 98 | 107 |

[1] Invited attendance on basis of refereed papers only

[2] Numbers suppressed by introduction of industrial groups attending on a full-cost paying basis and relative remoteness of meeting venue in Norway.

**3.12** Process Tomography Database

The ECAPT tomography database was established to provide a central service for the collection and dissemination of references and other information regarding Process Tomography. The database manager presented a report. on developments and activities at each meeting of the management committee. It is planned to maintain the database as long as interest is shown by the Process Tomography research community.

3.121 Database Access

The database was initially set up under the UNIX operating system running on a MIPS RS2360, based at the University of York, UK, and was later moved to a SPARC 10 UNIX system. Access to the database for customised searches was initially made available by electronic mail and the complete database was distributed in various formats as shown below.

1. by sending mail to the information server running at York, requesting complete copies of files held by the server
2. by logging in to the database server and searching for specific items
3. by requesting IBM or Macintosh format diskettes with the unformatted data
4. by requesting IBM or Macintosh format diskettes with the data in a proprietary format known as EndNote

A detailed description of the method of accessing the database was published with the papers from the first technical meeting and copies of this were subsequently distributed by the ECAPT office to those requesting it. Help was also available from the database manager at York. Subsequently access has been made available through the World Wide Web and, although email communication with the database manager is still available, the other methods of distribution have been suspended.

In 1995 the Manager reported the successful conversion of the complete database for access through the World Wide Web; this required a full graphics browser such as NCSA Mosaic or NetsCape. Alternatively" a terminal interface such, as Lynx could be used. The database had been provided with a simple' search engine through which the user can select the years of interest and can enter keywords in any or all of the basic fields of author, subject, publication and abstract, to direct the search.. The user 'can also download selected material to their local system for inclusion in bibliographies. Detailed instructions regarding access to the database through the World Wide Web have been distributed widely and presented at all recent EC APT meetings.

3.122 Database Usage

In 1993 the database manager reported on usage of the database during the first 2 years of operation and reported 180 individual requests under category 1 above; 2540 log ins, providing an unknown number of references on each login under catagory 2; 2(I requests in category 3 and 4 requests in category 4. He reported that although the total number of queries to the database has been encouraging. the level of use had begun to decline. This was probably because after the initial query (to stock a local database), the rate of return (new references) on the database is relatively low. In addition, apart from a few exception, the rate of additions to the database from outside York was low. It was not possible to establish any realistic figures for remote access after this date. Changes to the communication protocol Is used, problems with the remote access system and the 'replacement of the MIPS computer system meant that a new access monitoring system would need to be established and resources to implement this have not been available. Further it was not possible to establish figures for usage via'/ he World Wide Web for the same reason.

3.123 Encouraging and Extending Bibliographic Material

Several initiatives were proposed to extend the, database, - some of -which have been implemented.

i. Theses; both, MSC and PhD thesis data. Details of theses would include an abstract and a complete list of references. Research Groups have been relied upon to provide this material with some success to date.

ii. Other published material. The database had been extended by regular database searches but the indexing of commercial databases' is such that it is not always the best way of collecting data. It was considered that the maintenance of the database would be improved by actively seeking references from research groups rather than relying on the groups sending in contributions. A proforma for this was proposed and subsequent reminders have provided a small number of additions.

iii. Software. It was proposed that the database be made available for the storage and distribution of common software tools. A. documentation standard was drafted in 1993 and an experimental system for C and Motorola DSP codes was tested at York. Access to the system is identical to the rest of the database. Guidelines for C code documentation were developed and a notice about this appeared in ECAPT Newsletter , number 3. Progress in this area was slow and only software from work at York has been included up to now.

iv. Partners. A cross reference database for academic and industrial organizations Test Data. With a number of groups evaluating algorithms for speed and accuracy, it seemed that both standard "dummy" and experimental data, accessible to all would allow some common standards and comparison between systems to be made. Storage and distribution of this test data and the resultant benchmarks seemd to be within the database remit and a proposed documentation standard was distributed. No further progress has been made so far.

v. Research involved in the ECAPT programme had been established to promote the formation of effective partnerships. This contains a listing of the academic, industrial and research groups which had submitted status reports in 1994 together with their stated project aims and has been updated in 1995. The data may be searched in a similar way to that of the main database; the user may specify keywords in the Country, Group and Project Aims field to direct the search.

3.13 Annual Published Report

Papers from the annual technical workshop were published to provide a record of papers presented for use by those attending the workshop and for sale to the wider scientific community,.

*Process Tomography - 199.7: Implementation For Industrial Processes* (Papers- from ECAPT '95 at Bergen)
Editors: MS Beck, BS Hoyle, MA Morris, RC Waterfall, RA Williams
1995, UMIST, £50.00

*Process Tomography - A Strategy for Industrial Exploitation - 1994* (Papers from ECAPT '94 at Oporto)
Editors: MS Beck, E Campogrande, EA Hammer, MA Morris, RC Waterfall, RA Williams, 1994, UMIST, £50.00

*Process Tomography - A Strategy for Industrial Exploitation - 1993* (Papers from ECA PT '93 at Karl sruhe)
Editors: MS Beck, E Campogrande, MA Morris, RC Waterfall, RA Williams, 1993, UMIST, £40.00

*Tomographic Techniques for Process Design and Operation (* ?apers from ECAPT'92 at Manchester)
Editors: MS Beck, E Campogrande, MA Morris, RC Waterfall, RA Williams, 1993, Computation Mechanics Publications, £95

3.14 Status Reports

It was foreseen that certain techniques would develop to a state where a design report, or a feasibility report, should be made available. Reports on the following were published during the year indicated.

1. EIT Resistance (1993)
2. Electrical Capacitance Tomography (1993)
3. Electrical Charge Tomography (1993)
4. Electromagnetic Tomography (1993)
5. Optical Tomography (1993)
6. Instrument System Modelling and CAD (1993)
7. Process Tomography for Model Verification (1993)
8. Ultrasonic and Acoustic Process Tomography (1995)
9. Multi-sensor tomography (1995)
10. Image Reconstruction (1995)
11. Velocity Imaging (1995)
12. Dataprocessing Hardware (1995)

3.15 Collaborative Projects

'Many collaborative projects emerged during the course of the Concerted Action. Notable research partnerships included: -

| PARTNERS | AREA OF RESEARCH |
|---|---|
| University of Bergen/UMIST | Capacitance Tomography |
| UMIST/University of Aveiro | Electromagnetic Tomography *(Brite EuRam Contract Number BRE2-0604; Project Number BE- 7961-93)* |
| UMIST/University of Hannover | Capacitance Tomography |
| Lancaster University/Lawrence Livermore National Laboratory | Resistance Tomography |

Partnerships which developed for industrial testing included:-

| PARTNERS | AREA OF RESEARCH |
|---|---|
| UMIST/Process Tomography Ltd/Du Pent | Capacitance Tomography |
| UMIST/Exeter/Crossfield Chemicals | Capacitance tomography |
| Exeter/UMIST/Unilever | Resistance Tomography |
| Bergen/CMR | Capacitance + Gamma-ray |
| Bergen/CMR/UMIST/Elf/BP Norway/ Statoil/Rogaland University Centre | Capacitance Tomography |

Many of these collaborative' projects are still in progress.

### 3.2 Programme Management

Management of the Programme was effected by a cross-disciplinary committee. The inaugural meeting in Brussels in 1991 outlined the ECAPT objectives and criteria for the first annual technical meeting. The second, third, fourth and fifth meetings of the' management committee took place during the annual technical meetings and formally reviewed the progress towards these objectives during the previous year and outlined policy for action during the coming year.

Members of the Advisory Management Committee have been as follows:-

| | | |
|---|---|---|
| Dr D Agoropoulos | Shell Research BV (Netherlands) | 1994-5 |
| Dr D C Barber | Royal Hallamshire Hospital, Sheffield (UK) | 1991-4 |
| Professor M S Beck | UMIST (UK)<br>*Co-ordinating Editor, Annual Report* | 1991-5 |
| Professor J-C Bolomey | SUPELEC, *(France)* | 1993-5 |
| Professor A R Borges | University of Aveiro, (Portugal) | 1991-5 |
| Mr E Campogrande | Brite EuRam | 1991-5 |
| Mr J A Dell | University of York (UK)<br>*Database Manager* | 1993-5 |
| Mr R B Edwards | Unilever Research '(UK) | 1991-5 |
| Professor E Hammer | University of Bergen (Norway) | 1991-5 |
| Dr C P Lenn | Schlumberger Cambridge Rest arch (UK) | 1991-5 |
| Dr J Morris | MIRO then Independent Consultant (UK) | 1991-5 |
| Mrs M Morris | UMIST (UK)<br>*Programme Administrator* | 1991-5 |
| Professor F Mesch | University of Karlsruhe (Germany) | 1991-5 |
| Professor A Naylor | BNFL/UMIST (UK) | 1991-3 |
| Profesor R Pallas-Areny | University Polytechnic of Catalunya (Spain) | 1991-3 |
| Dr R Samson | Shell Research BV (Netherlands) | 1995 |
| Professor B Scarlett | TU Delft (Netherlands) | 1991-5 |
| Dr R W Taylor | University of York (UK)<br>*Database Manager* | 1991-3 |
| Dr R C Waterfall | UMIST (UK)<br>*Meetings Coordinator* | 1991-5 |
| Professor R A Williams | UMIST/University of Exeter (UK)<br>*Programme Manager* | 1991-5 |

During the period of the contract an ECAPT office at UMIST in the Department of Chemical Engineer-i ng dealt with day-to-day administration unc er the direction of a part-time Programme Administrator (Mrs M Morris) and the Programme Manager (Professor R Williams). In order to plan and coordinate activities Pro fessor Williams and the management team based at U M 1ST met regular] y and between meetings were in frequent and regular "contact by electronic mail, fax, post and telephone. This arrangement worked extremely well for the entire duration of the programme and there were only favorable comments as to pre-conference administration on the assessment forms.

As soon as the ECAPT office had an electronic mail connection established in 1992 email was used to communicate with partners. As more and more partners established connections to the Internet this became increasingly the preferred method of day-to-day communication. This was especially so between committee members. By the end of the programme the Management team had decided that in any future activity most communications would be delivered exclusively by electronic means in the form of e-mail to individuals and a World Wide Web site address for newsletters. To help with this the programme administrator established a contact address book and e-mail distribution lists on the administration PC and made sure that e-mail addresses formed part of published contact details.

A database of contact details was set up as soon as the programme began. This was regularly updated and the names of those who registered an interest in receiving future information about the programme were added. A total of 386 names were on the database by the end of the project in September 1995. These people had actively indicated that they wished to remain on the project mailing list either because they were actively involved in research or practice or wished to keep in active touch with the subject area.

The ECAPT office produced 4 newsletters during the programme. The EC APT newsletter served the dual purpose of introducing prospective participants to the ECAPT programme by giving background information and the programme contact address, and also highlighting the work of particular groups whose work would be of interest to existing participants. It also reported briefly on the previous technical meeting and gave information of general interest,

A mobile poster display setting out the objectives and encouraging membership of EC APT was prepared and exhibited at several international level meetings. For example, an invited presentation was made at the prestigious International Fine Particle Research Institute Meeting in July 1992. Members of ECAPT have presented papers concerning tomography and its industrial applications to several organisations in addition to the International Fine Particles Research Institute, the Institute of Physics, the Institution of Electrical Engineers and several [institution of Chemical Engineers meetings. A display and video was prepared and exhibited at the 5th Conference on Industrial Technologies held in Brussels from 6-8 December 1994.

## 4. Results

.4 books; 4 technical meetings; over 200 technical papers and an electronic (Internet) database service.

*Patents*

UMIST: "Electrical resistance tomography" F J Dickin, R A Williams and M Wang, PCT application GB95/00520, filed March **1994.**

EXETER: "Characterisation of flowing dispersions" R A Williams and F J Dickin, GB application GB9522060.4 filed 27th October 1995.

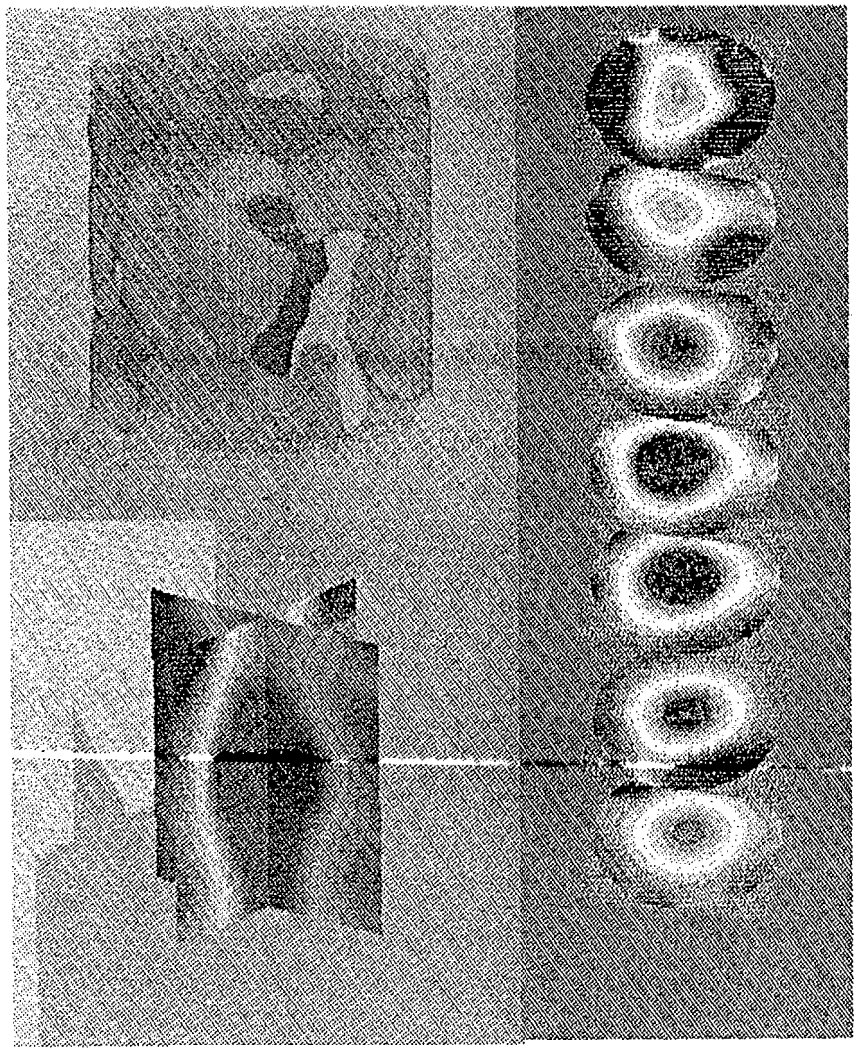
## 5. Conclusions

The, programme has been particular y effective in encouraging interchange of ideas and rapid progress of multidisciplinary research in applying tomo graphic techniques to meet specified industrial needs. An active community has been established including an electronic database. High quality research has been undertake n with significant industrial impact, as" evidenced by the publications output describing results of industrial and academic collaborators

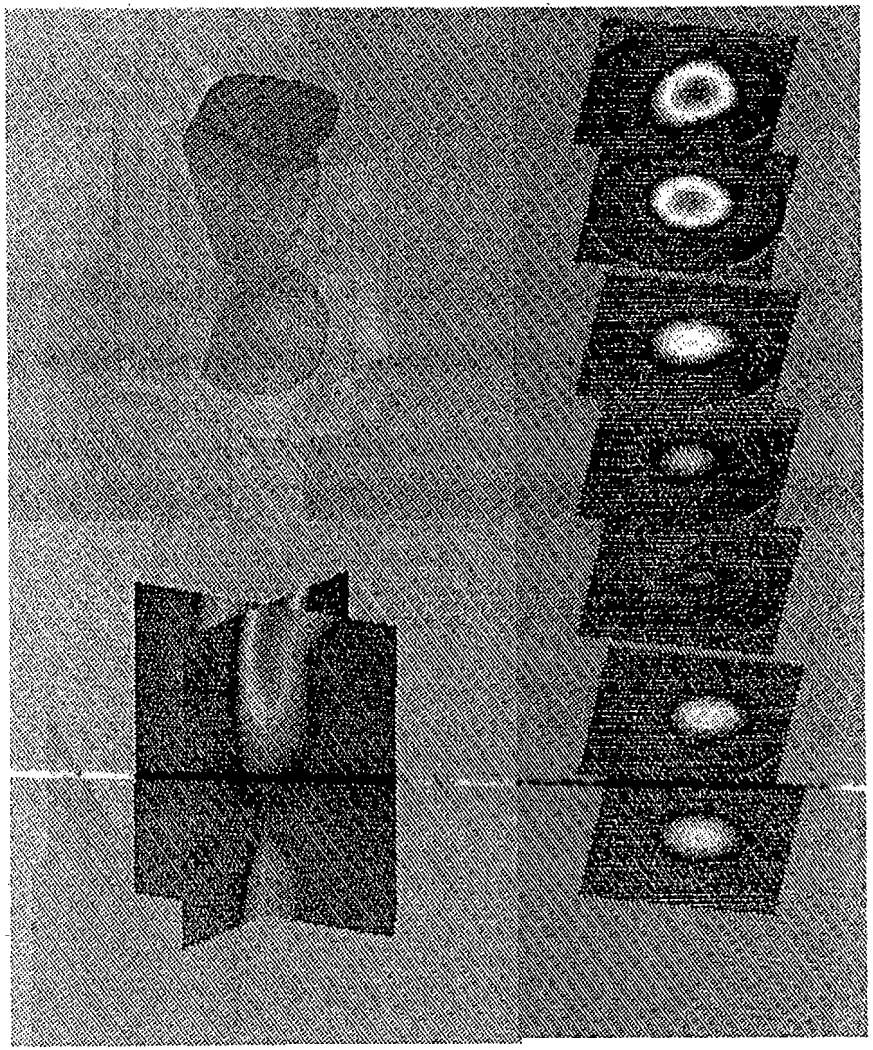
## 6. Acknowledgments

This project was funded by the European Community under the Brite/EuRam programme; contract number BREU-04 12, Project Number BE-4015-90

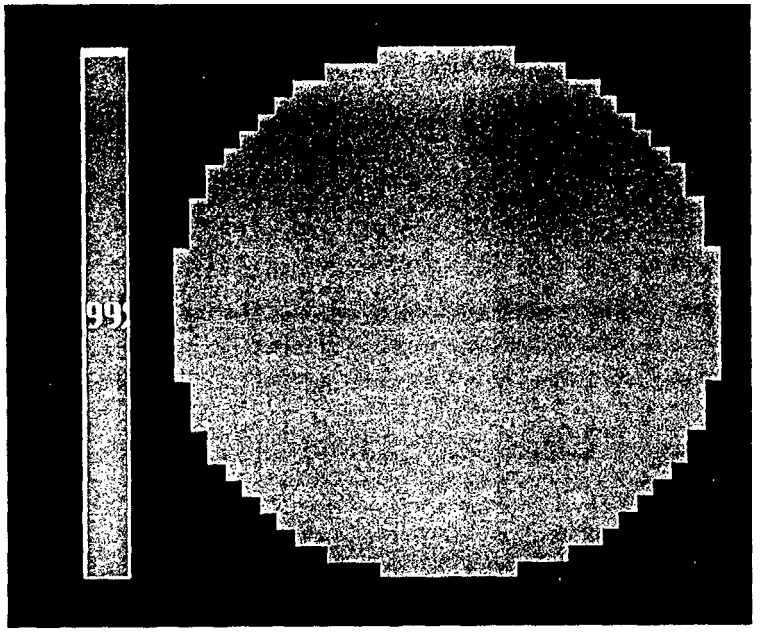
# Distribution of Gas Voidage



*Gas was injected at a flow rate 2.7m³/min. with stirrer switched-off*

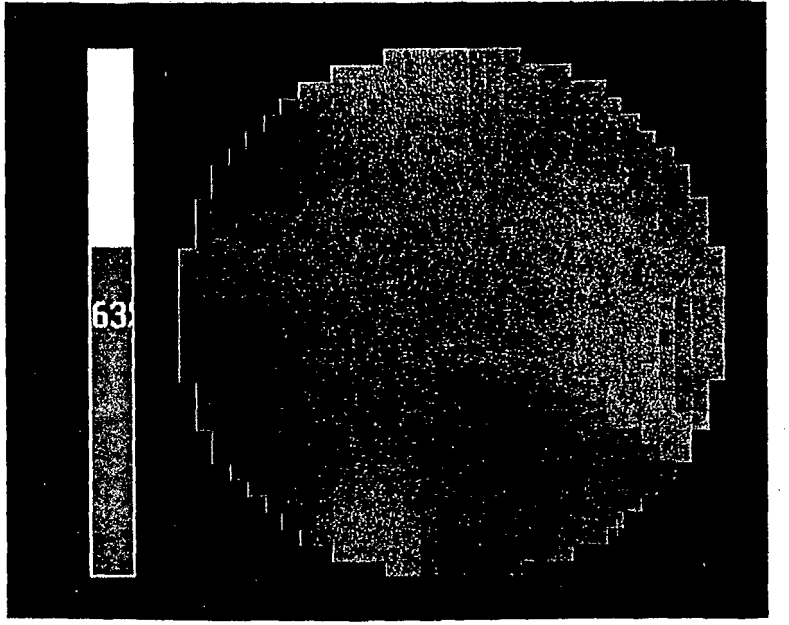


*Gas was injected at a flow rate 2.7m3/min. to the vessel stirred at 100 rpm*




a

fully compacted


B

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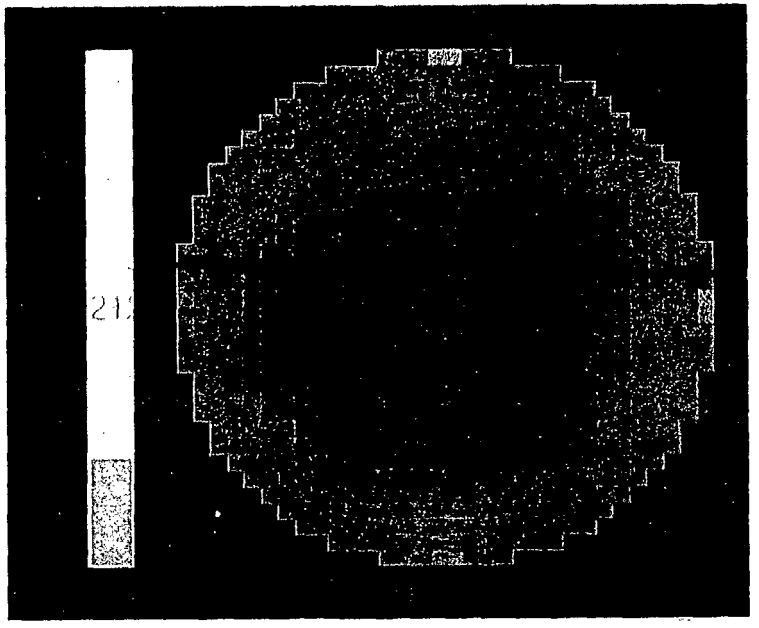
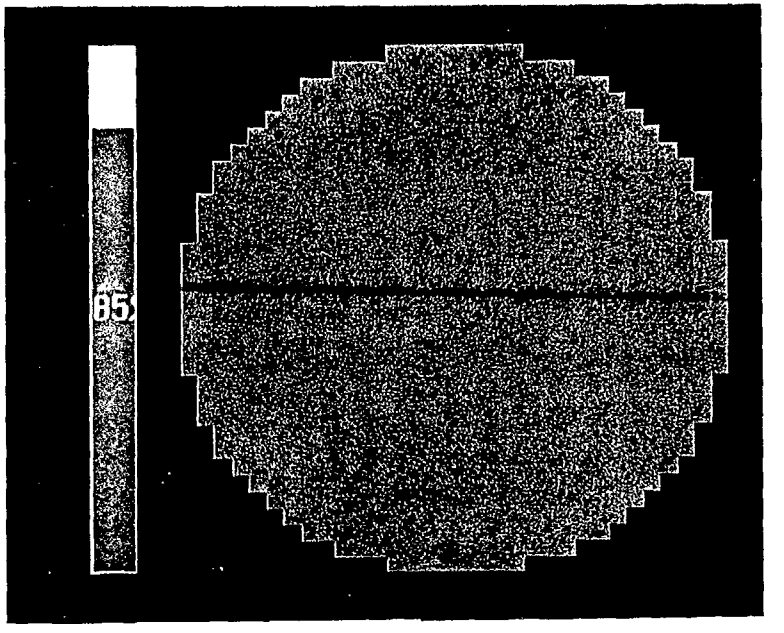



C

f uidised =21%




D

incompletely compacted after fluidisation

# ECT images of epoxy powder in 150mm dia. fluidised bed