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Innovative Training Network

TOMOCON

Deliverable Title

Preliminary Sensor Design with Basic Parameters for Demonstration

Description

This deliverable describes the fundamental tomographic sensor designs for the four industrial demonstration cases, including fundamental physical principles, electronics and data processing features, ways of implementation and operation in the respective process spaces, basic sensor geometries and materials, required electricity and media supply.

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Dissemination Level: **Public**

Revision Sheet

Revision Number	Purpose of Revision	Effective Date
0	Initial Issue	10.09.2018

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Preliminary Sensor Design with Basic Parameters for Demonstration

Tomography-controlled Microwave Drying of Porous Materials, ESR14 and ESR15

We have written Matlab/Netgen code to develop the forward model for Electrical Capacitance Tomography and COMSOL Multiphysics based forward model is developed for different geometrical configurations of Microwave Tomography. These models include the sensor designs with basic parameters for ECT and source (transmitter) modelling and placement of receivers for MWT. In the case of ECT, the forward model is solved with Finite Element Method (FEM) and in the case MWT, with FEM and also with Method of Moments (MoM). With numerical simulations, we can test different types of sensor geometries for ECT and desired radiation sources with different receiver parameters for MWT. These test runs will be used when designing the prototype sensors for laboratory tests and for the final demonstration. Computer simulations with different sensor designs are carried out during the autumn 2018 and the first prototype sensors for ECT and MWT will be built and tested in 2019.

ECT sensor design, ESR14

In the case of ECT simulation model for imaging moisture content of dried foam, we can test sensor design parameters such as size, shape and number of measurement electrodes and guard electrodes. Also of interest are the locations of the electrodes, location of the screen as well as the distance of the electrodes from the object to be imaged. The final configuration for the lab experiments is obtained through extensive simulations with different parameter setups and the quality of the reconstructed images (moisture contents) is the measure for choosing the best design option. Figure 1 shows an example of an ECT electrode configuration having 22 measurement electrodes, deployed uniformly around the domain in a two-dimensional manner.

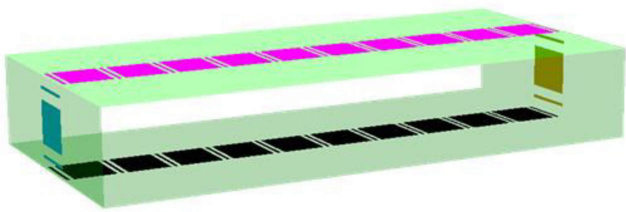

Figure 1. A setup of an ECT sensor design. Colored patches denote the measurement electrodes and the light green area is the boundary of the domain used in the simulations.

Using this configuration, the first results of the permittivity estimation of the imaging area are obtained by solving both forward and inverse problems. To solve the inverse problem, difference imaging method is used which estimates the difference of the object permittivity with respect to a reference permittivity which in our simulation is $\epsilon_r = 4$. Figure 2 shows the simulated domain and the position of the target with a different level of permittivity.

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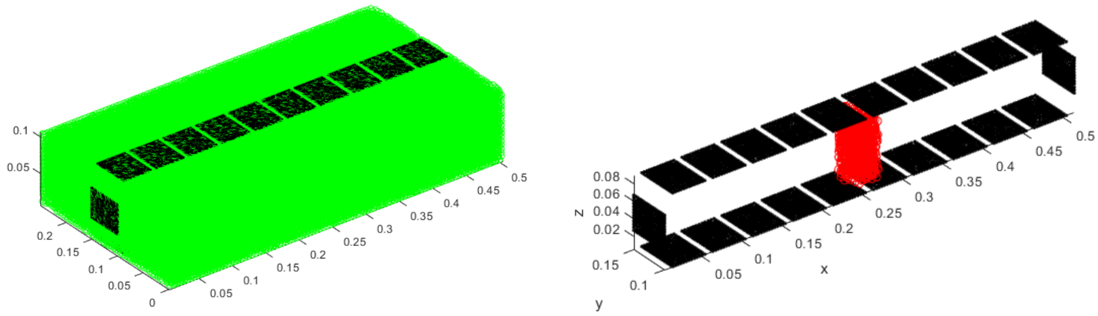

Figure 2. The green area shows the domain with relative permittivity $\epsilon_r = 4$ and the red area is the position of target with relative permittivity $\epsilon_r = 15$.

Estimated permittivity through the whole domain using 3D reconstruction is depicted in Figure 3. In the target position, we should have $\Delta\epsilon_r = 11$ and zero in other places.

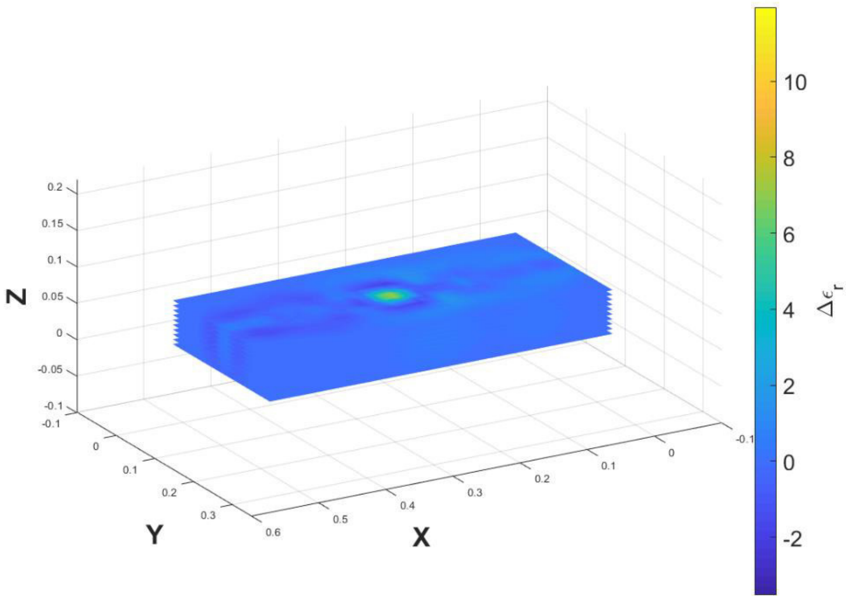

Figure 3. Estimated change of the relative permittivity distribution.

MWT sensor design, ESR15

With the MWT simulation model for imaging the moisture distribution of dried foam, we can investigate sensor design parameters such as size, shape, and number of sensors. Also of interest are the distance, frequency range, and scanning angle of the sensors with respect to the object to be imaged as well as the influence of different boundary conditions such as conveyor belt, and metallic parts of the HEPHAISTOS microwave system that will be used for the demonstration. A comprehensive number of numerical experiments with different model configurations and the quality of the moisture content reconstructions guide the measurement system to be built. Figure 4 shows an example of a MWT configuration at 2.45

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GHz having a total of 15 receiver sensors (highlighted with red arrows) and one transmitting sensor (highlighted with a black arrow). The snapshot shows how the foam with a uniform relative permittivity equal to 1.397, located in the middle of the picture (highlighted with black lines), interacts with the transmitted electric field.

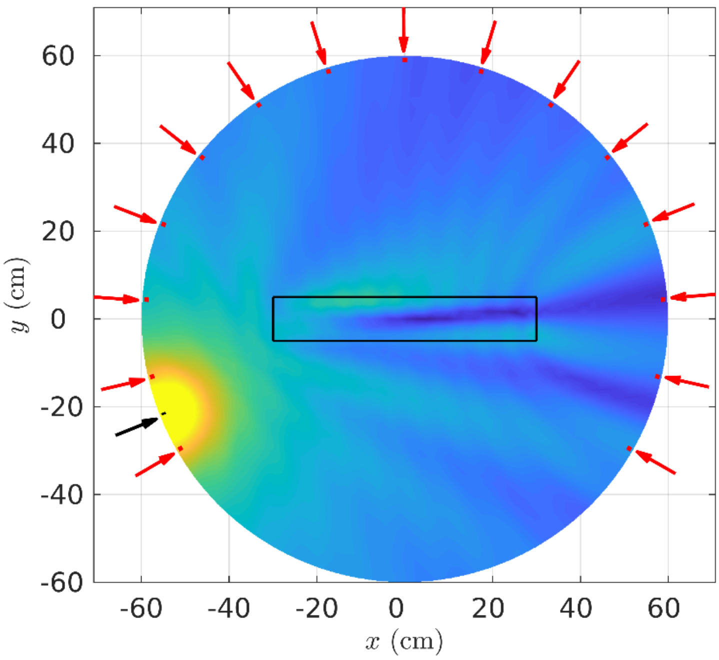

Figure 4. An example sensor configuration for the MWT at 2.45 GHz. Snapshot visualizes the norm of the total electric field demonstrating how the foam interacts with the transmitted electric field.

Tomography-controlled Continuous Metal Casting, ESR2

Contactless Inductive Flow Tomography (CIFT) will be used for imaging the dominant two-dimensional flow structure of liquid metal in the mould. By applying a primary magnetic field to the melt and measuring the flow induced (secondary) magnetic field perturbation outside the fluid volume, the flow structure in the melt can be reconstructed solving a linear inverse problem. A new sensor consisting of a pair of excitation coils as well as of 7 magnetic field sensors along each narrow face will be designed and build for the demonstrator. Figure 5 shows a preliminary sketch of the new sensor and the electromagnetic brake.

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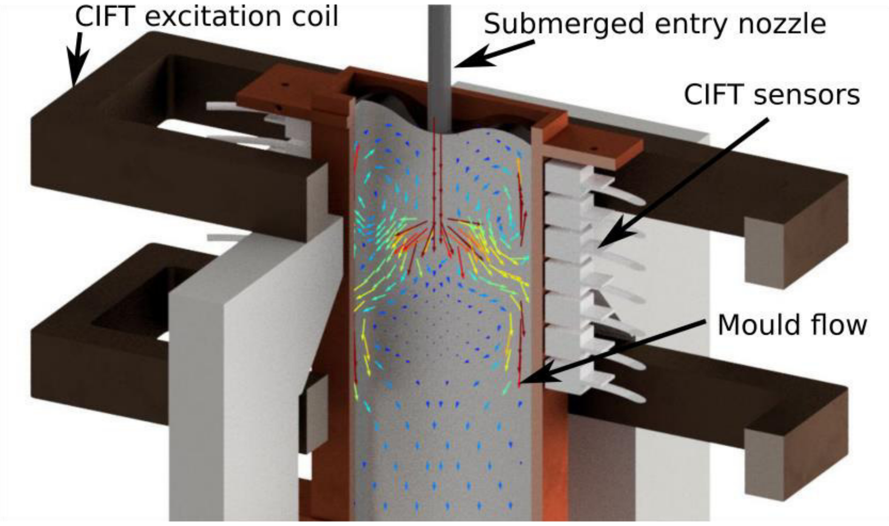

Figure 5. Sketch of the mould with the pole shoes of the electromagnetic brake, the excitation coil pair below and above the pole shoes, and the magnetic field sensors for CIFT.

The advantage of this configuration is the negligible effect of the ferromagnetic parts on the flow induced magnetic field, which will be measured by the magnetic field sensors. This allows the use of the standard linear inversion technique for CIFT and avoids the development of a new non-linear inversion technique. However, the effect of the ferromagnetic parts on the excitation magnetic field still has to be considered. A further important aspect is a very stiff connection between the magnetic field sensors and the excitation coils in order to achieve a robust measurement of the magnetic field. Additionally, the effect of the varying strength of the magnetic field of the electromagnetic brake has to be investigated and compensated, if necessary.

For measuring the flow induced magnetic field, existing gradiometric coils with 2x160 000 turns in combination with a 16 channel, 24-AD converter will be used. Previous measurements showed that this type of sensor is less sensitive to changes of the environmental magnetic field. In order to develop the new excitation coils, a model of the electromagnetic brake has to be built in COMSOL. This allows the design of the excitation coils which have to generate an excitation magnetic field with the strength of about 1 mT in the mould. Additionally, the forward and inverse solver for CIFT, which are written in C++, will also use this simulated excitation magnetic field. The forward solver allows the calculation of the flow induced magnetic field, which is necessary for the design of the excitation coils and the arrangement of sensors as well as for the virtual demonstrator. Since the flow simulations will be carried out by OpenFAOM, an interface is already implemented which can directly read the velocity fields from an OpenFOAM case. A mesh study for the forward and the inverse problem are on the way in order to achieve an optimal flow reconstruction.

ESR12

Magnetic induction tomography (MIT) sensors for filling regime observation in the submerged entry nozzle (SEN) is designed. MIT will be applied for imaging conductivity distribution inside the vessel. Configuration of coils as exciter and detectors is critical in order to obtain a satisfactory forward model, sensitivity, and it must be adjusted to the specific sensing case. Two-phase flow regime in the SEN contains a liquid metal jet as well as argon gas. A set of inductors (either commercial or special design) are fitted enveloping the SEN (made of PMMA). Each of which will be excited sequentially by current driver; while the others act as a

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detection to measure induced voltage. The SEN is filled with liquid metal in such fashion to represent flow regime and gas inclusion. Preliminary simulation has been conducted for observing the region of interest to obtain the desired information.

Sensor model is built in COMSOL with geometry of 8-coil enclosing cylindrical (as SEN) area with diameter 15mm. The object is placed in the centre of the sensing area and set as liquid metal with conductivity match to GaInSn (σ = 3.2E6 S/m) used for the demonstration. The simulation studies magnetic field where each coil is injected by ac current (100mA) with a given frequency (100Hz) to generate flux which will invoke eddy current on the object. Induced voltages on receiving coils are acquired as a set of combinatorial measurement necessary for tomography image reconstruction. A simple single-step algorithm using a pre-determined sensitivity map confirms the object's distribution.

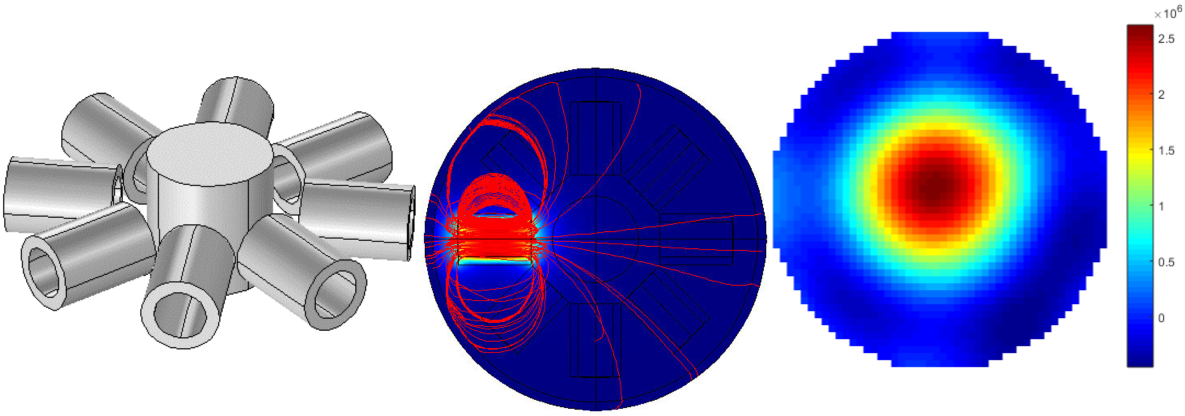

Figure 6. MIT sensor model with object inclusion (left); magnetic flux density and field streamline simulation (centre); image reconstruction (right).

Dual-sensor comprises electrical capacitance tomography (ECT) and MIT sensor is currently being modelled and will be further simulated for final construction. Two level of electrodes are assembled enveloping tube. Capacitive sensors made of copper plate are formed in eight rectangular sets attached to the tube, whereas the other layer consists of inductors. Vessel diameter is 15 mm to fit the SEN, each cylindrical coil size is 6.5mm diameter to 8.5mm of height, and copper electrode is 20mm x 20mm square.

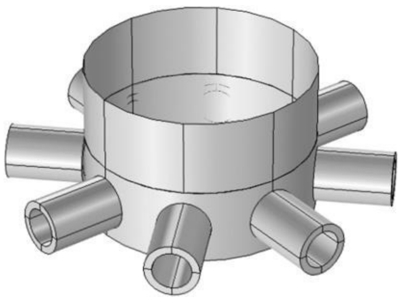

Figure 7. Combination of ECT and MIT sensors.

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Tomography-controlled Inline Fluid Separation

WMS sensor design, ESR 1

Wire-mesh sensors (WMS) introduced by Prasser et. al. [1] have been widely used to study two-phase and multiphase flow phenomena in the last decade. Even if the technique is intrusive, the easy application and its high spatial and temporal resolution allows to discover many details on flow structure and give excellent quantitative results on gas and liquid holdup and spatial distribution.

Two types of wire-mesh sensors exist which work based on measuring electrical properties of fluids.

While conductivity type of wire-mesh sensors is used for estimation of the gas holdup in conducting liquids like water, based on the difference in the conductance of the two fluids, the capacitance wire-mesh sensor [2] is a further development of the technique for non-conductive fluids. Later measures the electrical permittivity of the fluids in a cross section of a pipe or vessel. The measurement principle bases on a multiplexing scheme allowing the fast acquisition of measurements from NxM crossing points by use of an electronics with only N transmitters and M receivers. Therefore, two planes of parallel wires, separated by a short distance, are arranged perpendicular to each other. Sensors with 16x16 wire electrodes can be scanned with up of 10,000 frames per second. The wires of the first plane (transmitters) are sequentially supplied with an excitation signal, while the electrodes of the second plane (receivers) are sampling the signal, which is transferred through the currently present medium in the crossing point of the receivers with the excited transmitter electrode, all simultaneously. The local instantaneous signal is a DC (conductivity) or an AC (capacitance) current and depends on the local electrical properties of the media within the crossing point. The receiver stages consist of a trans-impedance amplifier followed by signal conditioning and sampling/digitizing stages. The measured data are stored into a PC and processed offline to calculate local holdups, phase fraction profiles and secondary parameters as bubble size distributions or radial profiles. Figure 8 and figure 9 show the measuring principles of the two WMS systems. Details on the techniques can be found in [1, 2].

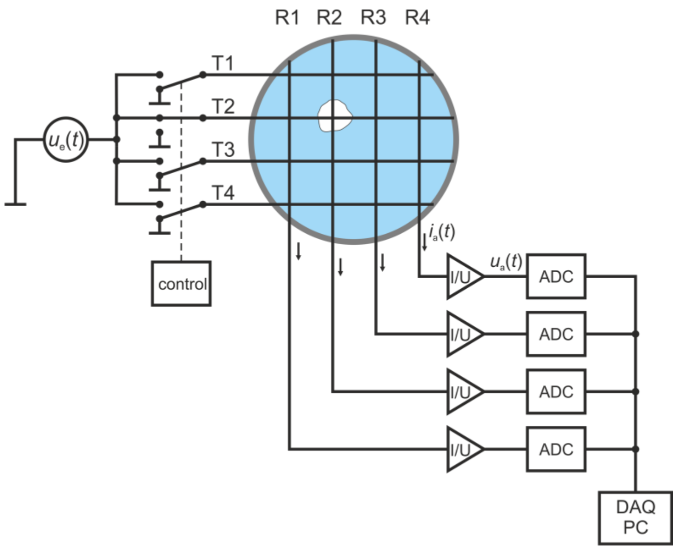

Figure 8. Simplified scheme of a conductivity type of wire-mesh sensor with electronics.

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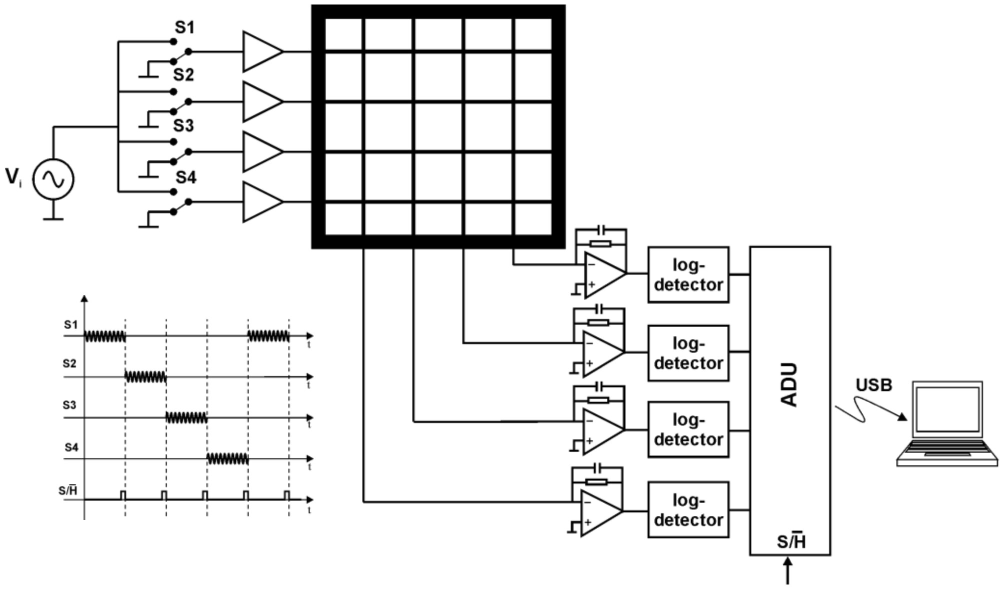

Figure 9: Simplified scheme of a capacitance type of wire-mesh sensor with electronics and timing diagram.

For the inline-fluid separation demonstration project originally a capacitance type of wire-mesh sensor was planned to be implemented. Due to the decision to go for an air/water demonstration experiment the final decision was taken to use the conductivity type instead. Since the sensor will be installed into a DN80 test facility, it has been decided to go for 24x24 electrodes giving a final resolution of roughly 3.3 mm. This is a good compromise between flow obstruction and spatial resolution. The wire diameter will be 300 µm which allows slug flows with high velocities without the risk of wire disruption. Preliminary tests at a vertical pipe section with swirl element at the TOPFLOW test facility have revealed that the stability and diameter of the resulting gas core after the swirling element of the phase splitter mainly depend on the two following parameters:

a) cross sectional void fraction and
b) mixture velocity.

For a calculation of structural velocities a set of two wire-mesh sensors have to be mounted behind each other for velocity measurement based on cross-correlation. The sensor distance will be adopted by three different intermediate rings of 10, 20 and 40 mm for later optimisation based on the superficial velocities. Since the sensors will be applied to low pressure / low temperature flow loop only, the flanges will be made from acrylic for additional visual inspection.
For controlled fluid separation, an online data processing is needed. An algorithm for online calculation of the instantaneous cross sectional holdup has already been implemented. Currently, we are working on implementation of velocity estimation, since cross correlation always need a history of a certain number of frames.

References:

[1] Prasser, H.-M.; Böttger, A.; Zschau, J.
A New Electrode-Mesh Tomograph for Gas-Liquid Flows
Flow Measurement and Instrumentation 9 (1998) 111-119

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[2] Da Silva, M. J., Schleicher, E.; Hampel, U.
Capacitance wire-mesh sensor for fast measurement of phase fraction distributions
Measurement Science and Technology 18(2007)7, 2245-2251

ESR 10

While the wire-mesh sensor is installed upstream of the swirl element, electrical sensors are installed downstream because the liquid-gas mixture is conductive. Capacitance-based sensors are excluded and resistance/impedance point sensors are privileged. This choice comes also with a lower acquisition rate to measure the resistance between pairs of electrodes, which is in line with reducing the overall data handling process. Currently, two sensor topology options are envisaged which are as follows:

1. Two planes of 8 electrodes each placed at an equal distance between the top of the swirl and the pick-up tube considering a pick-up tube position at 30cm above the swirl. This implies two planes at 10cm and 20cm respectively.
2. One plane of 8 electrodes above the swirl and one plane in the swirl with electrodes uniformly installed in the channels between blades (See figure 10).

While option 1 can be useful to investigate the misalignment of the vortex during phase separation on the other hand option 2 can give information about the gas distribution in the swirl channel and its potential effect on vortex positioning.

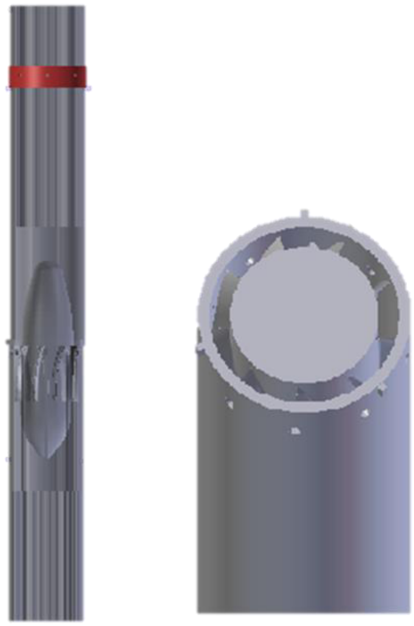

Figure 10: 8 Electrodes above the swirl and inside.

Currently, a total of 16 electrodes is planned to agree with standard ERT/EIT systems. Tubes and swirl parts need to be drilled since point electrodes need to be in contact with the conductive media.

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M.A Sattar (ESR 10) starts in mid-August 2018 a month' training secondment at ROCSOLE LTD. to be acquainted with Electrical Tomography sensor design. This will give him more insights and ideas to better design the sensor layout for the Inline fluid separation (IFS), taking into account industrial constraints.

Tomography-controlled Batch crystallisation

Batch crystallisation evaluation using the Electrical Resistance Tomography sensors (Rao G. (ESR 11), Wajman R. and Jackowska-Strumillo L.)

A conceptual model of a laboratory-based batch reactor to observe the crystallisation process has been designed. The reactor is functionally compatible with the reactor at Lappeenranta University of Technology (LUT), Finland, where the CFD simulation of the crystallization process will be developed. The reactor consists of a transparent plexi vessel with mounted controllable stirrer and heating spiral. Additionally two holes have been drilled in the upper cover to place a thermocouple and to add the antisolvent solution. The test capacity of this reactor is about 3 liters. It consists of two prototypes of frames for introducing the circular-ring evaluation architecture. The test CAD models were developed using the software AutoCAD and blender 3D. The first frame was 3D printed using the Nylon as a printing material. For 3D printing Ultimaker 3 was used. A copper spiral was used for temperature control inside the reactor. A provision of stirrer within the top cover to be controlled in the feedback loop using servo motor was also planned. The initial test-runs using this reactor would be conducted in September 2018. The study and comparison with the simulations would be done during the secondment of Guruprasad Rao (ESR 11) from October-December 2018 at LUT in Finland.

ERT sensor architecture

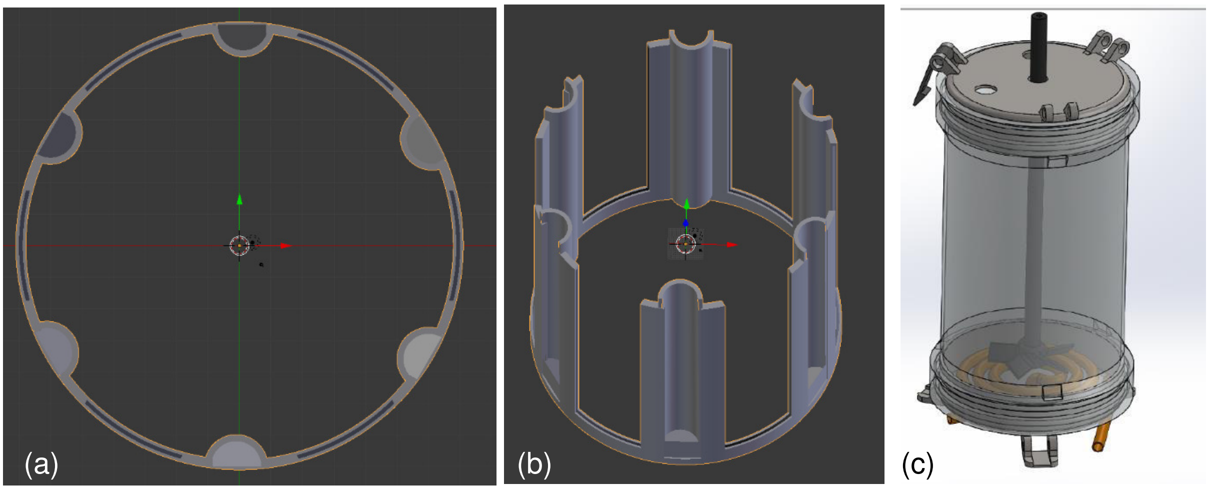

Figure 11. (a) Top view of the frame (b) User perspective and (c) conceptual model design of laboratory reactor.

Also a concept of universal, portable 3D ERT sensor has been developed. The architecture of the sensor frame is shown in Fig. 11a and 11b. It allows to place circumferentially the preferred sensors electrodes with constant vertical distance. After the placement of the

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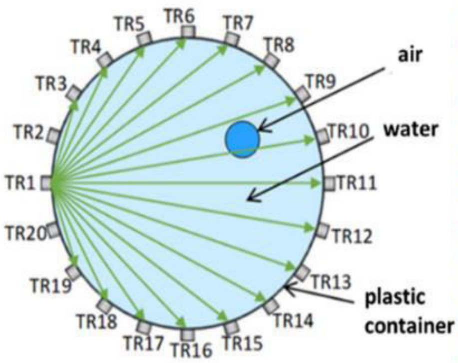
sensor electrodes, the evaluation of the crystals and calibration would be conducted. First 1D, then 2D and finally different 3D sensor architectures will be tested. The measurements will be obtained using AC-ECT/ERT acquisition unit. The tomography system has 32 independent channels. Every channel can be configured as excitation, measurement or floating mode. A 16bit ADC (Analog-to-Digital Converter), a 12bit DAC (Digital-to-Analog Converter) and a 16bit microprocessor are used. The hardware consists of 8 front-end Printed Circuit Boards (PCB), each containing 4 channels, and a microcontroller PCB. The 32 electrodes can be composed as 1-4 planes or mounted freely as a 3D sensor.

ESR13

Our work is based on developing ultrasonic transmission tomography for detecting two-component high-acoustic impedance mixture. We used an ultrasonic tomography system, developed by Research and Development Centre Netrix S.A., using fan-shaped beam scanning geometry with 20 sensors circle wise topology. Furthermore, a 2D transmission-mode approach was implemented to simulate the physics of the experiment in order to reconstruct from acoustic velocity profile, assuming the wave propagation as the propagation of line integrals.



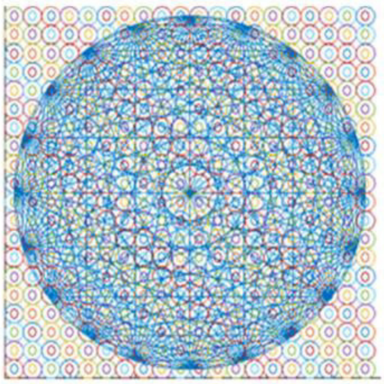


Figure 12. Left: Geometry of sensors of 2D fan beam tomographic system. Middle: Rays in the scanned region of the experiments.

According to the difference on the penetration depth for given particle concentrations, we calculated the time of flight of the signals to characterize the space domain and effectively detect the different material composition inside the liquid mass. Finally, various inverse modelling (LBP, Tikhonov, TV) was employed for image reconstruction from the projection data using single steps and iterative algorithms to compare comprehensively the results for 2D transmission mode using lab data.

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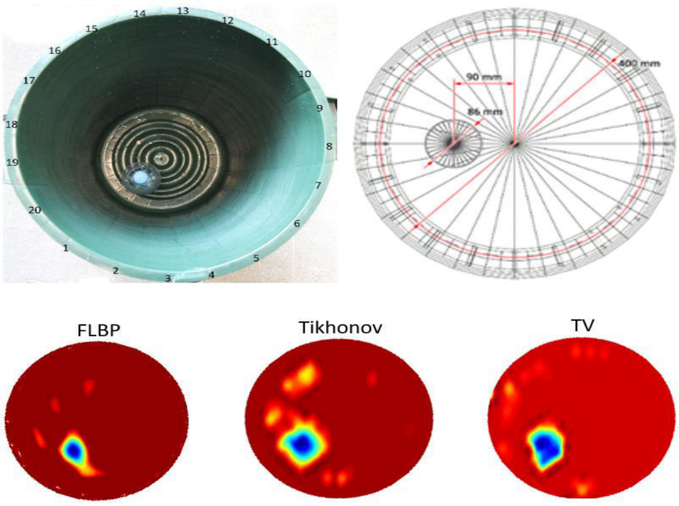

Figure 13. Left: Model of the tested object and image reconstruction results using various methods.

Dissemination Level: **Public**

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