# Review:Electrical capacitance tomography

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**Abstract**

**Electrical capacitance tomography (ECT) is used in industries for studying the chemical processes taking place inside pipes and chemical vessels. It is a widely popular and nonintrusive technique for sensing and measuring the spatial distribution, voidage, and velocities of flow of the materials in a pipe. It helps the chemical process engineer in indirectly visualizing the chemical process taking place inside the vessel which until now was not possible. Capacitive sensors are employed to sense the change in permittivity of the materials inside the vessel. The acquired data is used to construct permittivity distribution images, which aid in understanding the nature of activities taking place inside the vessel, by calculating various key parameters related to the chemical process. The images can also help in deciding the future course of control actions needed to be taken if required. The advantages of the technique are non-intrusive nature for measuring the capacitances, simple transduction principle, fast response, simple and efficient algorithm used to generate images of reasonably good resolution. The sensors employed are capacitance sensors which are cost effective and easy to construct. This paper discusses the principle, system description, merits, demerits and applications of ECT. Recent developments to improve the performance of ECT system are also discussed.**

*Keywords*- **capacitive sensors, Electrical Capacitance Tomography,multiphase flows, non-intrusive, permittivity**

## I. INTRODUCTION

Process Imaging or process tomography provides real-time cross-sectional images of the distribution of materials in a process. By analyzing two suitably spaced images it will be possible to measure the direction and speed of material movement. Hence from this knowledge of material distribution and movement, internal modes of the process can be derived and used as an aid to optimizing the design of the process [1].

In recent years, applications of process tomography, as a robust non-invasive tool for direct analysis of the characteristics of multiphase flows, have increased in large numbers. Process tomography involves utilization of tomographic imaging methods to manipulate data from remote sensors, to obtain precise quantitative information from inaccessible locations. ECT is considered to be the most powerful tool among other available tomographic techniques because of its high-speed capability, robust, low construction cost, effectiveness, and portability, no exposure to radiation hazard, high safety and suitability for small or large vessels [2].

ECT is an emerging technique aimed at the non-invasive internal visualization of industrial processes like mixing, separation and two-phase flow. ECT involves the measurement of changes in capacitance from a multi-electrode sensor due to the change in permittivity of materials being imaged, and the reconstruction of cross-sectional images using the measured data and a suitable algorithm [3]. ECT enables insight into the material distribution within a closed vessels and consequently, into the governing mechanism in the process, without disturbing the process itself [4].

## II. ELECTRICAL CAPACITANCE TOMOGRAPHY SYSTEM

ECT measures and displays the concentration distribution of a mixture of two insulating i.e. dielectric fluids, such as oil, gas, plastic, glass and some minerals, located inside a vessel. The measurement can be completely non-invasive if the vessel walls are non-conducting [5] [6] [7]. A basic ECT system shown in fig 1 consists of -

1. Capacitance sensor which comprises of an array of electrodes attached to periphery of the pipe which is to be imaged.

2. Capacitance measuring unit to acquire and process the signals obtained from the capacitance sensor.

3. Control computer to reconstruct and display the permittivity distribution image using the data obtained, and to monitor and control the process taking place inside the pipe.

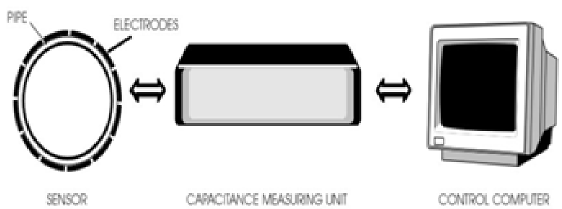



Fig.1 Basic Electrical Capacitance Tomography system

All the measured and calculated parameters are normalized to reduce the errors in measurement. The control computer employs the Linear Back Projection Algorithm (LBPA) for generating permittivity distribution images. The images are displayed on a 1024 square pixel grid using a suitable graduated color scale to indicate the variation of permittivity. The permittivity images are also used to generate appropriate control signals, which decide the future course of a chemical process [6].

Measurement Principle

The basic idea is to surround the vessel with a set of electrodes (metallic plates) and to take capacitance measurements between each unique pair of electrodes. From these measurements, the permittivity distribution of the mixture (which is related to the concentration of one of the fluids) can be deduced. Vessels of any cross-section can be imaged and an example of a simple cylindrical 8-electrode sensor is shown in fig. 2 below [5].

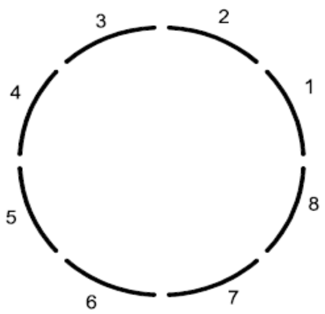



Fig.2. Typical electrode arrangement

## III. SYSTEM DESCRIPTION

Sensor

The sensor consists of an array of electrodes attached to the periphery of the pipe which is to be imaged. The pipe can be fitted with external electrodes or internal electrodes. Figure 4 shows their corresponding cross-sectional views [6]. An outer earthed screen, which surrounds the measurement electrodes, minimizes external electrical noise. For a sensor with N electrodes there are N(N-1)/2 single-electrode pairs and hence N(N-1)/2 independent capacitance measurements. The measurement capacitance of an ECT sensor depends mainly on the electrode size. For a given number of electrodes, the capacitance is proportional to the axial length of electrodes. Typically, the length of electrodes is selected about 10cm [3].

Capacitance Measuring Unit

The capacitance measuring unit shown in figure 5 constitutes of the necessary electronic circuitry to measure and condition the signals received from the capacitance sensor. The various electronic circuits employed to accomplish these objectives are AC bridges for measuring capacitances, amplifiers, phase sensitive detectors, and filters [6].

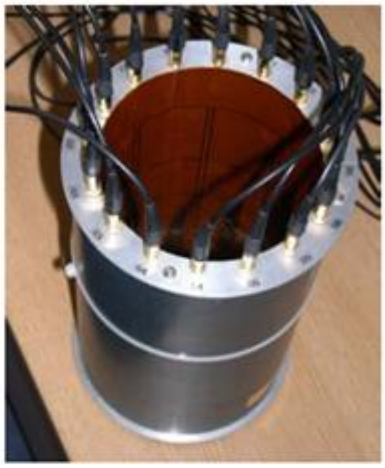
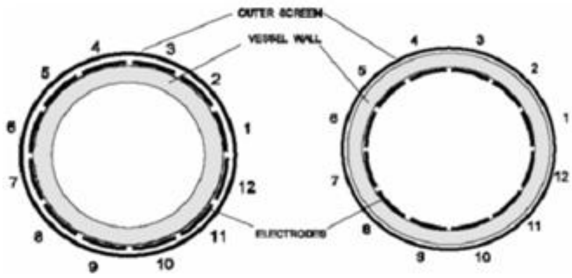


Fig.3. Practical ECT sensor




External electrodes Internal electrodes

Fig.4. Cross-sections of sensors with external and internal electrodes

Control Computer

There are a multitude of operations that need to be performed by the control computer. The main role of the control computer is in constructing the permittivity distribution images using data acquired by measuring the inter-electrode capacitances. An algorithm implemented in the control computer performs the task of constructing the permittivity distribution images from measured value of capacitances. In this process the Control computer acts as a visual display unit. The permittivity distribution images are used to interpret the process taking place inside the pipe [6].

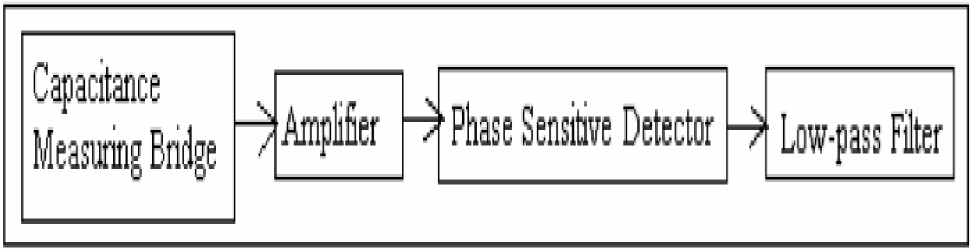



Fig.5. Building blocks of a capacitance measuring unit

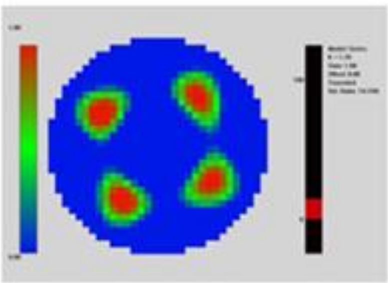
Image reconstruction

The resolution of an ECT permittivity image is limited by the number of independent measurements that can be made. It is not possible to obtain a unique solution for each image pixel when the number of pixels in the image exceeds the number of capacitance measurements. Furthermore, image distortion can occur because ECT is an inherently soft-field imaging method (the electric field is distorted by the material distribution inside the sensor). However, in many cases, the contrast between the permittivity of the materials inside the sensor is small, resulting in only limited image distortion. This allows approximate linear algorithms to be used to relate the capacitance measurements to the pixel values in the image and vice-versa. [8].

Though the back projection algorithm is a simple and fast algorithm, it is based on some unrealistic assumptions and its accuracy is unsatisfactory [9].

ECT images

ECT images are normally of relatively low resolution (a 32 x 32 pixel grid is typical) but they can be captured at high speed. With existing technology, image data can be captured at 100 frames per second for a 12 electrode sensor and displayed on-line. Higher image capture rates (up to 300fps) can be achieved for 8 or 6 electrode sensors. In the sample images shown below, a red/green/blue color scale shows areas of high concentration as red and areas of low concentration as blue [5].



(a) 4 plastic rods

Fig.6. sample ECT images

## IV. RECENT DEVELOPMENTS IN ECT SYSTEM

Grouping technique for electrodes

Typically, an ECT system consists of multiple electrodes that are symmetrically mounted inside or outside a cylindrical container. During the period of a scanning frame, an excitation signal, e.g., an alternating current (ac) voltage is applied to one of the electrodes, and the remaining electrodes are kept at the ground potential, acting as detector electrodes. Subsequently, the voltage potential at each of the remaining electrodes is measured, one at a time, by the measurement electronics to determine the interelectrode capacitance. A large number of electrodes contribute to improving the resolution of the image reconstruction but lead to a smaller surface area of the respective electrodes. This will cause decreased magnitude of the interelectrode capacitance and a lower signal to-noise ratio (SNR). To overcome this in recent years, the grouping technique has been introduced to combine two or more electrodes into one segment to increase the magnitude of the received signals, as illustrated in Fig. 7.

As a result, the total number of independent measurements performed by the ECT electronics in each scanning frame will be twice as high (12 versus 6) as that of a conventional four-electrode sensor. This leads to higher resolution for better image reconstruction. The advantage of grouping for improved measurement resolution while maintaining the SNR has been demonstrated in [4].

Multiple excitation capacitance polling (MECaP) technique MECaP technique is used to significantly increase the image scanning speed of ECT. Unlike the traditional ac method where an excitation signal is applied to one electrode

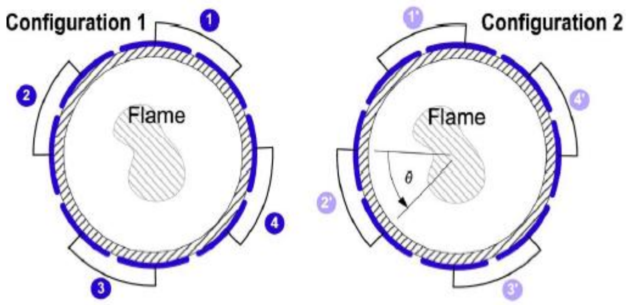



Fig. 7 Grouping configurations for an ECT sensor operated in the four segment mode.

at each time step, the MECaP method simultaneously applies multiple excitation signals to multiple electrodes on the ECT sensor and simultaneously measures the capacitances, thereby significantly increasing the scanning speed [4].

Due to availability of high speed computing and modern electronics it is possible to use LBPA techniques equipped with high number of iterative procedures and still capture image at a sufficiently high rate [6].

The image produced by LBPA shows a blurred area, while image produced is clear by the iterative algorithm. This indicates significant improvement by iterations [10].

## V. MERITS AND DEMERITS OF ECT

**Merits of ECT:**

i. Attractive method for real imaging of industrial processes, because of its inherent simplicity, rugged construction of the tomographer and high-speed capability.
ii. It is non-intrusive nature for measuring the capacitances.
iii. Simple transduction principle, simple and efficient algorithm used to generate images of reasonably good resolution.
iv. Low-cost and easy to construct, having fast response and versatile.
v. Efficient for detecting permittivity changes inside a chemical vessel, when the vessel contains non-conducting or dielectric materials.
vi. No radiation, non-intrusive and non-invasive, and robust in hostile environments with high temperature and high pressure [6] [8].

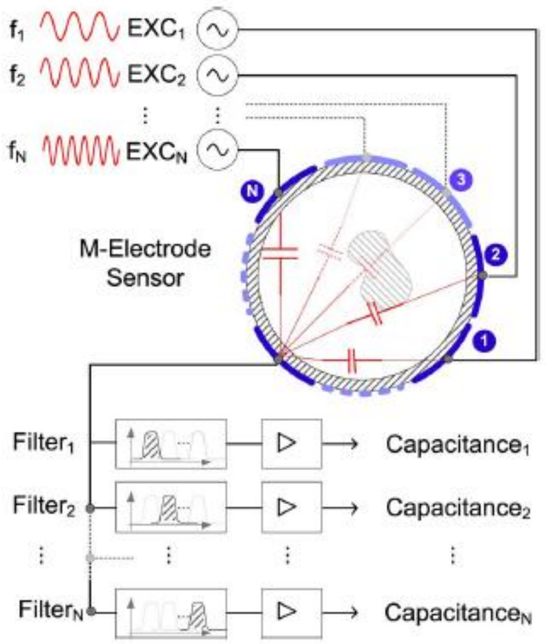



Fig. 8. MECaP technique in an M-electrode ECT system with N (N ≤ M − 1) excitation signals simultaneously applied.

**Demerits of ECT:**

i. Low-resolution imaging methods. The image resolution of ECT is approximately 10% of the sensor diameter.
ii. In capacitance process tomography, the tomograms reconstructed are often distorted.
iii. The technique provides erroneous results when used to image vessel containing conducting materials [6] [8] [11].

## VI. APPLICATIONS OF ECT

ECT is most successful when applied to materials such as oils, plastics, dry powders and under favorable circumstances pure water, all of which have low electrical conductivity. It can also be used to image flames and combustion and is often used with mixtures of two different dielectric materials, as the permittivity distribution corresponds to the concentration distribution in this case. ECT can be used in a wide range of applications, including monitoring fluidized beds, flow rate measurement in pneumatic conveying systems, product uniformity monitoring and sensing, high-speed check-weighing and the monitoring of oil-gas flows [5][6][11]. ECT is used to study Gas-water droplets distribution in wet gas separators [11] and mass flow measurement in pneumatic transport [12].

## VII. CONCLUSION

Permittivity distribution images are the means of studying a chemical process where two materials having different relative permittivity react inside a vessel. This is achieved by positioning capacitance sensors around the periphery of the vessel which is an ECT system. ECT system can be used for studying the chemical process inside a pipe and helps in viewing the contents which hitherto were not visible. Various information like, spatial distribution, volume ratio, and velocity of flow of the materials inside the chemical vessels can be computed by examining the permittivity distribution images. Though the advantages of ECT include low cost, non-intrusive technique for measurement, and fast response, the technique provides images of low resolution. MECaP method may be used to further increase the scanning speed by directly applying multiple excitations on the electrodes.

The LBPA technique is used to reconstruct permittivity distribution images in real-time but suffers from poor spatial resolution. But for a good image the resolution needs to be increased further. This can be done by implementing iterative methods. There is still scope for improvement in image quality through advances in sensor design, measurement electronics and protocol, computing hardware and reconstruction algorithms.

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