CHAPTER 1

INTRODUCTION OF STUDY

1.1 Introduction

This thesis presents the detailed study on the application of Electrical Capacitance Tomography (ECT) and Delta-P technique for two-phase bubble column under controlled operating conditions. The study is based on the assessment and analysis of experimental results obtained through a two-phase air-water bubble flow experiments carried out on an ECT sensor which is performing as a co-current bubble column. This installation of ECT sensor (i.e. co-current bubble column) is being done on the two-phase test rig in the department of Electrical and Electronic Engineering, in Universiti Teknologi PETRONAS, Malaysia. This chapter describes the background of the entire work and also gives brief synopsis of the thesis structure.

1.2 Project Background

A two-phase flow is one of the most common flows in nature as well as in industrial applications; it covers gas-solid, liquid-liquid, solid-liquid and gas-liquid flows. Among these, the gas-liquid flows can be encountered in wide variety of industrial applications including boilers, distillation towers, chemical reactors, oil pipelines, nuclear reactors, etc. The measurement of two-phase flow parameters such as flow regime and void fraction is considerably important and plays an important role in operational safety, process control and reliability of continuum processes [1]. The identification of two-phase flow regimes is essential because of their significant influence on heat and mass transfer phenomena. Similarly, the measurement of two-phase void fraction is necessary in many industrial applications because it is used for characterizing the bubble column hydrodynamics. It is the key physical value for determining numerous other parameters, such as two-phase density, viscosity and is of fundamental importance in models for predicting flow pattern transitions [2].

The customary approaches (e.g. quick-closing valves and optical fibre probe) for two-phase flow measurement usually separate the two-phases first and then measure the mixture as individual components. Moreover, it may also result in the disruption of incessant industrial processes [1], [3]. In order to overcome the above limitations and achieve more reliable measurements of two-phase flow, some non-intrusive measuring techniques are used such as:

i. Tomography
ii. Differential pressure method
iii. Radiation
iv. Laser
v. Nuclear Magnetic Resonance (NMR)

The above mentioned techniques are considered as reliable and promising for two-phase flow measurement and possess valuable advantages. Out of these techniques, Electrical Capacitance Tomography (ECT) is considered as a most practical one to measure two-phase flow. They do not hinder the nature of the process and as well as non-contacted with the tested medium [4]. It can be defined as an electrical technique to study the direct analysis of an internal characteristic of the process plants based on [5];

i. Raw data inferential techniques or signal processing
ii. Image reconstruction of internal processes.

The ECT system comprises of three main units: electrical capacitance sensor, data acquisition unit and a control computer, which can be used for image reconstruction, interpretation and display. ECT is based on measuring capacitances of a multi-electrode sensor surrounding the periphery of a vessel or pipe containing two different permittivity materials. These measurements are used to reconstruct the permittivity distribution by using non-iterative image reconstruction i.e. linear back projection (LBP) and iterative image reconstruction i.e. iterative LBP algorithm [6]. Successful applications of ECT include imaging of two-phase gas-liquid mixtures in pipelines and gas-solid mixtures in fluidised beds and pneumatic conveying systems.

The second technique i.e. differential pressure method is also used to calculate the void fraction in an air-water two-phase flow. This method is used as benchmark for ECT measurement in a co-current bubble column. The measurement of void fraction via pressure difference is simple, economical, non-invasive and does not interrupt bubble column operation. In comparison with other methods like radiation attenuation, the pressure difference method is much safer [7].

The work presented in this study investigates the vertical co-current two-phase air-water bubble flow regime. This research work mainly focuses on the bubble flow regime, which can be characterized by vertically upward moving bubbles with maximum size is much smaller than the diameter of the containing column, dispersed in a continuous liquid phase. The bubble diameter is also an essential parameter in characterising the internal structure of two-phase bubbly flow and can be estimated by using the photographic technique. Finally, to estimate the void fraction in an air-water two-phase bubble column by using the electrical capacitance tomography and the differential pressure technique and then evaluate the difference in measurements by using precedent correlations.

1.3 Problem Statement

In process industries, the measurement of two-phase void fraction is considerably important for sustainable operations. As this parameter largely affect the mass flow rate of gas and liquid in a two-phase flow. The non-prediction of void fraction is inevitably be the cause of many industrial accidents such as loss of coolant accidents in nuclear reactor operations, sweet corrosions in sub-sea oil and gas pipelines and an in-efficient process control in chemical plants. Due to this reason, the void fraction is considered as a critical parameter for designing pipeline system in the above process applications. In case of any accident, a large amount of expenditure is required for the installation and replacement of pipelines. It is therefore, necessary to measure and control the void fraction for achieving safety, process efficiency, energy saving and quality assurance in the process applications.

1.4 Aims and Objectives

The aim of this research is to study and calculate the void fraction measurement in an air-water two-phase bubble flow by using Electrical Capacitance Tomography and Delta-P measurement. To accomplish this aim, following are the key objectives;

i. Development of an online co-current two-phase air-water bubble flow test rig and establish the compatibility of ECT in co-current bubble column.

ii. Analysis of bubble flow regime and bubbles characteristics.

iii. Computation of void fraction by raw data results and image or pixel analysis.

1.5 Research Approach

In order to achieve the aims and objectives, this research endeavour is divided into three main steps. The brief description of each phase is as follows:

i. *Literature Review*- It is a preliminary phase to start the research work. During this phase, a thorough review of preceding literature in journal publications; conference proceedings; relevant articles and books; and online resources were carried out. This stage is very important because it provides a basis to elicit all the embedded information that will help to address the scope of research.

ii. *Experimental Analysis*- It is the second and a practical step towards the accomplishment of the research objectives. It covers the design and construction of an experimental setup to study the two-phase bubble flow regime in a bubble column and subsequently an implementation of an electrical capacitance tomography technique on it. During investigations, static and dynamic types of experiments were performed on this test setup. The static tests only cover the low and high calibration of an ECT sensor whereas the dynamic test covers low, high and two-phase measurement of air-water bubble flow. The dynamic tests further classify the bubble flow regime into more sub-regimes for a detailed study.

iii. *Data Measurement and Analysis*- It is performed by using direct and indirect methods of measurement. The direct measurement includes the photographic image analysis of the bubbles characteristics. While the indirect method of measurement consists of raw and pixels data obtained from ECT and differential pressure measurements collected from delta-P in order to calculate the void fraction in a co-current bubble column for two-phase bubble flow regime.

1.6 Project Scope

This research scope comprises of three main parts of study. The primary task is the simulation of an ECT sensor using COMSOL Multiphysics (FEM Software) based on the physical dimensions of the sensor. The sensor was simulated by using a total of 12 electrodes mounted externally in order to calculate the capacitance of an ECT sensor. After sensor simulation, an experimental test rig was established for two-phase air-water bubble flow by using in-house facilities. This laboratory scale equipment is used to generate the phenomenon of void fraction in an ECT sensor (i.e. co-current bubble column) and its subsequent measurement and analysis by using the ECT technique and differential pressure measurements. Later, series of experiments were performed for the analysis of physical parameters of two-phase flow as well as investigate the bubbles characteristics by using an imaging technique for two-phase bubble flow.

1.7 Thesis Structure

Following this introductory chapter i.e. Chapter 1, the overview of the content of the remaining chapters of this thesis is briefly presented in this section.

Chapter 2 reviewed void fraction in co-current bubble column particularly with a particular emphasis on gas-liquid flow along with its industrial applications, measuring techniques and correlations. It also discussed flow measurement parameters and different flow regimes observed in a vertical two-phase bubble column and also review on the methods for flow regime detection.

Chapter 3 is divided into two parts. The first part presents the detailed study on the background of an ECT system, principle of operation, capacitance sensor description, calibration, capacitance measurement and its application. The second part focuses on the background and mathematical description of the differential pressure technique for void fraction measurement.

Chapter 4 describes the experimental facilities used in the accomplishment of research objectives. The metering section, the test section and the data acquisition system are the three main parts being focussed on. The later part of this chapter explains the experimental procedure, test matrix and how the measurements obtained from differential pressure and ECT for two-phase flow.

Chapter 5 is based on simulated and experimental results. It discusses the application of distribution models on homogeneous mixture of air-water two-phase bubble flow.

Chapter 6 presents the summary and a conclusion of this dissertation along with some recommendations for future work.