FLOW REGIMES IDENTIFICATION OF PARTICLES CONVEYING IN PNEUMATIC PIPELINE USING ELECTRIC CHARGE TOMOGRAPHY AND FUZZY LOGIC TECHNIQUE

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Dedication

In the Name of Allah, the Most Beneficent, the Most Merciful

My dearest husband, Mohd Zaki Hj Ab Razak

My beloved fathers and mothers
Hj Kamaruddin Idris and Hjjh Asmah Abd Kadir
Hj Ab Razak Ismail and Hjjh Shofiah Awang

My adorable daughters
Batrisyia and Hadhirah

My sisters and brothers

My valued friends

Thanks for the endless support, patience, believing in me, inspiring me, and encouraging me throughout my research.

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ABSTRACT

A detailed and accurate measurement technique for metering solids bulk pneumatic transportation often creates challenging problems to engineer and scientist. Problems occurred particularly due to spatial and temporal fluctuations of both the solid velocity and concentration during pneumatic transportation. During this development, it leads to the use of tomographic measurement techniques. A well-liked trend in the development of tomographic measurement techniques for research and production is the use of electrical techniques. One of the electrical tomographic techniques is electrical charge tomography or also known as electrodynamic tomography which offers inexpensive, non-invasive, simple and robust method for measuring particulate solids flow in pneumatic pipeline. In this research electrical charge tomography measurement is made by placing an array of 16 electrodynamic sensors evenly around circumference of pipe to detect the existence of inherent charge on the moving particles which passes through the pipe. The converted voltage signals received from the 16 electrodynamic transducers are captured and stored by data acquisition card which acts as interface between the computer and the transducers. The two most commonly methods for image reconstruction namely linear back projection algorithm and filtered back projection algorithm are employed to produce tomographic image. The signals captured are in range of mass flow rate between 110g/s until 500g/s. Matlab is exploited to compute the image reconstruction and visualise the tomogram for concentration distribution across a given cross section of pneumatic pipeline. Baffles of diverse shapes are inserted to create various flow regimes whereby fuzzy logic technique is used to identify these flow regimes. The major conclusions drawn from this research were the successful use of the fuzzy logic technique for flow regime identification and producing an improved image of filtered back concentration profiles for each flow regime.

ABSTRAK

Keperincian dan ketepatan kaedah pengukuran pengaliran sesuatu pepejal sering menimbulkan cabaran pada para jurutera dan ahli sains. Masalah berlaku disebabkan oleh perubahan ruang dan masa pada kedua-dua halaju dan penumpuan semasa pengangkutan pneumatik. Ekoran dari perkembangan ini ianya menjurus kepada penggunaan pengukuran kaedah tomografi. Arah aliran yang diminati dalam perkembangan kaedah pengukuran tomografi kepada institusi penyelidikan dan pengeluaran adalah penggunaan teknik elektrikal. Salah satu daripada teknik tomografi elektrikal ialah tomografi cas elektrik atau pun dikenali sebagai tomografi elektrodinamik yang menjanjikan harga yang murah, tak invasif, mudah, dan tegar untuk mengukur aliran partikel pepejal dalam talian paip pneumatik. Dalam kajian ini pengukuran tomografi cas elektrik dijalankan dengan meletakkan satu tatasusunan 16 penderia elektrodinamik yang sama jarak di lilitan paip untuk mengesan kewujudan cas pada bahan pepejal yang mengalir menerusi paip. Isyarat yang telah ditukar kepada voltan diterima dari 16 penderia elektrodinamik dikesan dan disimpan oleh kad perolehan data yang berperanan sebagai antara muka di antara komputer dan penderia-penderia. Dua kaedah pembinaan imej yang dinamakan sebagai algoritma unjuran balik linear dan algoritma unjuran balik terturas telah digunakan untuk penghasilan imej tomografi. Isyarat yang dikesan dalam lingkungan kadar aliran jisim diantara 110g/s hingga 500g/s. Perisian Matlab digunakan untuk menghasilkan pembinaan imej dan pemaparan tomografi untuk taburan penumpuan di kawasan keratan rentas paip. Penghadang pelbagai bentuk dimasukkan untuk mewujudkan pelbagai rejim aliran dimana teknik logik kabur digunakan untuk mengenal pasti rejim aliran tersebut. Kesimpulan utama dihasilkan dari kajian ini adalah penggunaan teknik logik kabur sebagai kaedah mengenal pasti rejim aliran dan menghasilkan imej profil penumpuan balik terturas yang lebih baik untuk setiap rejim aliran.

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LIST OF ABBREVIATIONS

2D	-	Two dimension
3D	-	Three dimension
ANNs	-	Artificial neural networks
ART	-	Algebraic reconstruction techniques
BP	-	Back propagation
DAS	-	Data acquisition system
ECT	-	Electrical capacitance tomography
ERT	-	Electrical resistance tomography
FBP	-	Filtered back projection
FBPA	-	Filtered back projection algorithm
GUI	-	Graphical user interface
HHT	-	Hilbert Huang Transform
Hz	-	Hertz
IMFs	-	Intrinsic mode functions
LED	-	Light emitting diode
LBP	-	Linear back projection
LBPA	-	Linear back projection algorithm
LLD	-	Liquid level detection
LS	-	Least square
PC	-	Personal computer
PDF	-	Probability density function
PT	-	Process tomography
PET	-	Positron emission tomography

SVM	-	Support vector machine
USB	-	Universal Serial Bus

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CHAPTER 1

INTRODUCTION

1.1 An Overview of Process Tomography and Its Development

Tomography is defined as imaging by section. It comes from the Greek word *tomos* which conveys the meaning of "a section" or "a cutting" or "a slice" and *graph* conveys the meaning of "picture". The Helicon Encyclopaedia defines tomography as the obtaining of plane section images, which show a slice through an object (Rahmat, 1996).

Early in 1826, a Norwegian physicist named Abel first published the concept of Tomography for an object with axi-symmetrical geometry. In 1914 Mayer developed the idea of tomography to fulfill the needs of medical non-invasive imaging technique. Then in 1917 an Austrian mathematician Radon extended the idea founded by Abel for objects with arbitrary shape. This was followed by Godfrey Hounsfield and Allen Cormack in 1979 who jointly received the Nobel Prize for successfully creating X-ray Tomography.

In the mid-1980s there was a rapid progress in several centers with Sheffield University and Royal Hallamshire Hospital in the United Kingdom as well as Wisconsin University and Rensselaer Polytechnic Institute in the United States of America taking major roles. Subsequently medical scientists acknowledged the capability of Electrical Impedance Tomography (EIT) for imaging human body safely and at low cost. In the medical area, tomography has been used to image swallowing, stomach emptying, lung ventilation and perfusion, pulmonary edema, blood clots, brain function, brain tumors and breast tumors.

Tomography seems to be used as an imaging tool for medical purposes. However, the concept of tomography is not limited to the medical field instead it has been utilized in many research areas. For instance, in the field of seismologic information regarding the distribution of temperature can be obtained by measuring arrival times of earth quake at numerous seismic stations distributed over the globe (Lee, 2007). In the middle of 1980s, a research group at the University of Manchester Institute of Science and Technology (UMIST) designed an electrical capacitance tomography for imaging multi-component flows from oil wells and in pneumatic conveyors.

Over the last decade tomography has been developed as a reliable tool for imaging various industrial applications which is commonly known as Process Tomography (PT) or Industrial Process Tomography (IPT). Process Tomography can be applied to many types of process and unit operations, including pipelines, stirred reactors, fluidized beds, mixers and separators. Depending on the sensing mechanism used, it is non invasive, inert and non-ionising. It is therefore applicable in the process of raw material; in large scale and intermediate chemical production; and in the food and biotechnology area (Alias, 2002),

The application of tomography in industries are also found in chemical, oil, gas, food processing, biomedical, pharmaceutical, and plastic product manufacturing. It has been used purposely for a better process control, optimization and efficient production (Sabit, 2005).

Process Tomography allows boundaries between heterogeneous compounds or homogeneous objects in a process to be imaged in real time using non-intrusive sensors. Information on flow regime, velocity profile and concentration distribution in pipelines or process vessels will be discovered from the image.

The basic concept of tomography is to install a number of sensors around the circumference of the pipe or vessel to be imaged. The information on the disposition and distribution of objects within its sensing zone will be disclosed. A tomographic image of the cross section of the object being captured by sensors are reconstructed and displayed by a computer and after that the image data can be analysed for improvisation. The basic components of any tomography measurement systems are integration between hardware and software. The hardware consists of elements like sensors, signal generator and data control, where as the software is used for signal reconstruction and image displaying. An overview of process tomography system is shown in Figure 1.1.

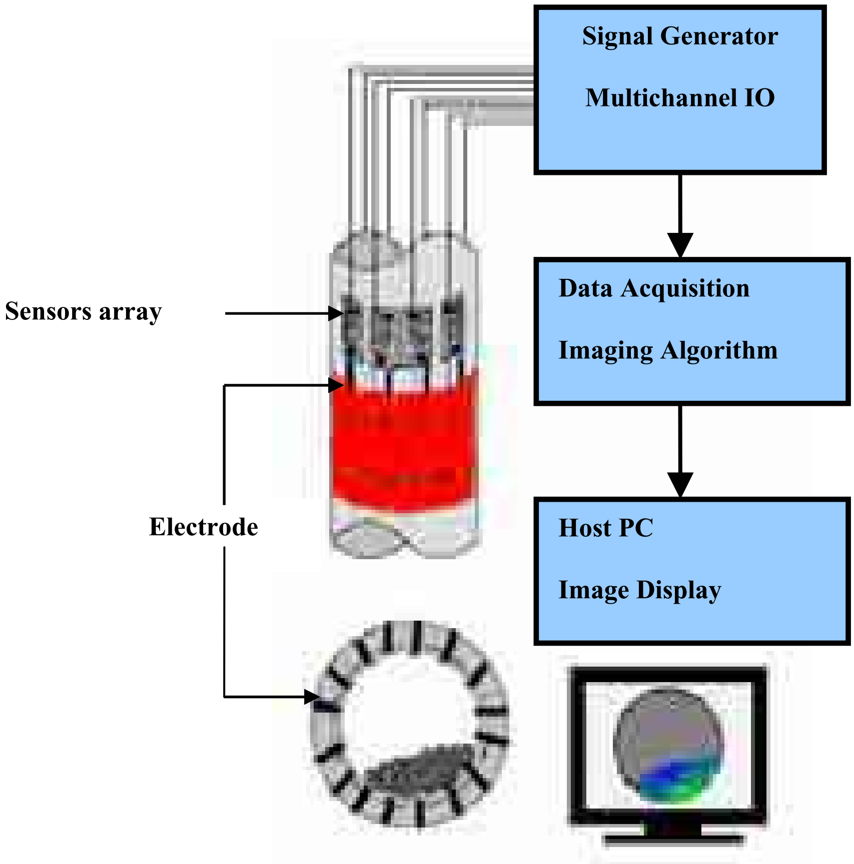

Figure 1.1: Overall schematic of process tomography system

Nowadays there is an increasing need to be acquainted with the exact way the internal flows in process equipment are behaving. These needs occur because industry is under pressure to utilize resources more efficiently and to satisfy demand and legislation for product quality and reduced environmental emissions (Rahmat, 1996). Tomographic instrumentation offers non-invasive technique and robustness to solve industrial needs. It also includes tomographic imaging methods to manipulate the data from remote sensors in order to obtain precise quantitative information from inaccessible location (Dickin et al, 1991).

The use of tomography would result in more rigorous and confident design basis for process equipment (Dickin et al, 1992), such as safety, cost saving in capital equipment, floor space and overall productivity. The other advantage of tomography technique is that the flow in particular pipeline can be monitored in more efficient manner and safety hazards in terms of charge accumulation and hot spots can be forewarned (Alias, 2002).

1.2 Problem Statement

The flow regime within the pipeline of a pneumatic conveying system, for a given particulate material may simultaneously exhibit several flow regimes throughout its length. If an unstable flow occurs it can result in vicious pressure surges which will increase both plant wear and product degradation problems. In addition, the identification of the flow regime at critical sections of pneumatic conveyor is fundamental to any void fraction estimate, upon which many standard measurements such as solids mass flow rate will depend. Insufficient air velocity may cause blocking within such system. Once blocking has occurred, it can be extremely difficult to remedy. Cross sectional imaging of the pipeline offers potential benefits in both control and fault monitoring of pneumatic conveying systems (Neuffer et al, 1999).

Electrical charge tomography has been used to visualize the particle distribution across a given cross section of pneumatic conveying system, whilst ensuring the information extracted may be used to achieve better control of the plant. However, a problem arises due to the non linear sensing mechanism of the electrical charge transducer (Green et al, 1995) which affected the accuracy of tomographic images calculated using linear back projection algorithm. This deficiency can be rectified by introducing the second algorithm called filter back projection algorithm.

The filter back projection algorithm combines filter masks with linear back projection to compensate for the lost signal strength at the center of pipe. On the other hand, filter masks are different for different flow regimes therefore prior knowledge of flow regimes being conveyed are necessary to determine the right filter mask (Sabit, 2005). This research investigates the use of fuzzy logic method to identify different types of flow regimes and furthermore produce improved concentration profiles.

1.3 Research Objectives

1. To develope the hardware of tomographic measurement system using electrical charge transducer or better known as electrodynamic transducer.

2. To identify the flow regimes of particles conveying in pneumatic pipeline using fuzzy logic approach.

3. To generate concentration profiles of solid particles over a cross-section of pneumatic conveyor using linear back projection and filtered back projection algorithms

1.4 Research Scopes

The scopes of the research are:

1. Develope a measurement system of electrodynamic transducer for pneumatic conveyor. The performance of the electronic circuit of electrodynamic transducer will be investigated.

2. Develop an application program using Labview for data capture system. Keithley KUSB-3116 data acquisition card is used to capture data from the sensors output.

3. Develop an application program using Matlab to obtain tomographic images of concentration profiles based on the data captured from measurement section.

4. Construct program using Matlab fuzzy logic toolbox for identification process of flow regimes.

5. Verify the accuracy of the developed system by comparing the predicted data with measured data.

1.5 Thesis Organization

Chapter 1 presents the general overview of process tomography, problem statement, research objectives, research scopes and thesis organization.

Chapter 2 reviews the different types sensing mechanisms of sensor used in tomography system. Discussion in this chapter is concentrates on the related works which similar to this research.

Chapter 3 describes the phenomenon of charging mechanism of solid particles in pneumatic pipeline, mathematical modeling of electrodynamic transducer and procedure how to calculate concentration profile.

Chapter 4 presents the principle of fuzzy logic and the propose method for flow regimes identification.

Chapter 5 describes the structure of electrodynamic tomography measurement system which includes the design of the circuit, the gravity flow rig, data acquisition and storage, and the software for interface between sensor and computer.

Chapter 6 presents the performance results of electrodynamic transducer, concentration profiles and tomographic images. The performance of fuzzy logic in identifying flow regimes process is discussed.

Chapter 7 discusses the conclusion, contribution of this research and recommendation for future research.

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