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CONCENTRATION PROFILING OF TWO PHASE FLOW IN A GRAVITY FLOW RIG USING OPTICAL TOMOGRAPHY

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Abstract. The objective of this paper is to present research on the use of an optical tomography method using infra-red sensors for real-time monitoring of solid particles conveyed by a gravity flow rig. The sensor comprised two orthogonal and two diagonal light projections to form upstream and downstream arrays in a total of four parallel projections. Collimating the radiated beam from a light source and passing it through a flow regime ensures that the intensity of radiation detected on the opposite side is linked to the distribution and the absorption coefficients of the different phases in the path of the beam. The information on the flow captured using upstream and downstream infra-red sensors is digitized by the DAS system before it was passed into a computer to be analyzed in order to reconstruct the cross section image. This investigation successfully developed and tested an infra-red tomography system to profile the concentration of two phase flow in a gravity flow rig.

Keywords: Concentration profiles; two phase flow; optical tomography; infra-red; solid flow

Abstrak. Matlamat kertas kerja ini ialah untuk membentangkan penyelidikan tentang penggunaan kaedah tomografi optik menggunakan penderia-penderia infra merah untuk pemantauan masa nyata terhadap zarah-zarah pepejal yang dialirkan oleh rig aliran graviti. Penderia terdiri daripada dua projeksi cahaya orthogonal dan dua projeksi cahaya melintang untuk membentuk deretan atas dan bawah menjadi empat projeksi selari. Penumpuan pancaran daripada satu sumber cahaya dan mengalirkannya melalui rejim aliran yang memastikan keamatan pancaran dikesan pada bahagian yang bertentangan disambungkan kepada agihan dan pekali serapan bagi fasa-fasa yang berbeza dalam laluan pancaran. Maklumat pada aliran yang diperolehi oleh penderia-penderia yang dipasang di bahagian atas dan bawah akan dijadikan dalam bentuk digital oleh sistem perolehan data sebelum ia dihantar ke sebuah computer untuk dianalisis untuk memaparkan keratan silang imej. Penyelidikan ini berjaya dikembangkan dan diuji menggunakan sebuah sistem tomografi infra merah untuk memaparkan kepekatan aliran dwi fasa dalam rig aliran gravity

Kata kunci: Profil kepekatan; aliran dwi fasa; tomografi optic; infra-merah; aliran pepejal

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1.0 INTRODUCTION

Tomography enables us to discover the complexities of structure without the need to invade the object [1]. It is a continuation from the early research involving x-ray tomography, which focused on how to obtain 2-D cross-section images of animals, human, and non-living things [2]. Within short time, the field of process tomography is growing rapidly. It is gaining its importance to apply into an industrial process from the widespread need for the direct analysis of the internal characteristics of process plants in order to improve the design and operation of equipment.

Process tomographic instrumentation must be relatively low cost and be able to make measurements rapidly, using an array of non- invasive sensors placed around the periphery of a process vessel [1] where it is possible to image the concentration and movement of components inside the measurement area. There are several types of sensing method in process tomography, where the sensing technique used does not disturb the nature of the flow field. The subsequent stage of any tomographic imaging system is to process the acquired data using an appropriate image reconstruction [3]. There are two types of tomographic reconstruction algorithms: analytic (e.g. Fourier inversion) and algebraic (e.g. algebraic reconstruction technique (ART)) [4]. The choice of the reconstruction algorithm is dependent on the tomography technique selected [5]. For an example, the transmission tomography technique (e.g. X-rays) used the analytic reconstruction algorithms (Fourier inversion and Filtered back-projection) and algebraic reconstruction technique for multiphase flow imaging, mixing study and fluidized bed imaging [3].

Optical tomography is an attractive method since it may prove to be less expensive, has a better dynamic response and be more portable for routine use in a process plant compared to other radiation-based tomography techniques such as positron emission, nuclear magnetic resonance, γ photon emission and X-ray tomography [6].

Investigation conducted by Chan [7] improved flow imaging using 16 alternating fan-beam projections with an image reconstruction rate of 20 fps, but this image reconstruction rate is not sufficient to achieve an accurate measurement of velocity as more projections are needed. Instead of using one light source, this project focused on using individual light source meaning one infra-red LED emitter for one photodiode. Sixteen photodiodes were combined with a signal conditioning system, and a data acquisition system.

2.0 SYSTEM CONFIGURATION

This optical tomography system used several projections between 0° and 180°, with an interval of 1°. In this project, the projection used a set of sensors (16×16) arranged in orthogonal and diagonal parallel position with each having 16 sensors, equally placed outside a pipe with 82 mm outer diameter and 78 mm inner diameter at 0°, 45°, 90°, and 135° projections. The orthogonal projection has a total of 32 sensors and the diagonal projection has 32 sensors. Hence, for both upstream and downstream position the total number of sensors used is 128 pairs of optical sensors. Figure 1 shows the arrangement of fiber optic holes for each projection.

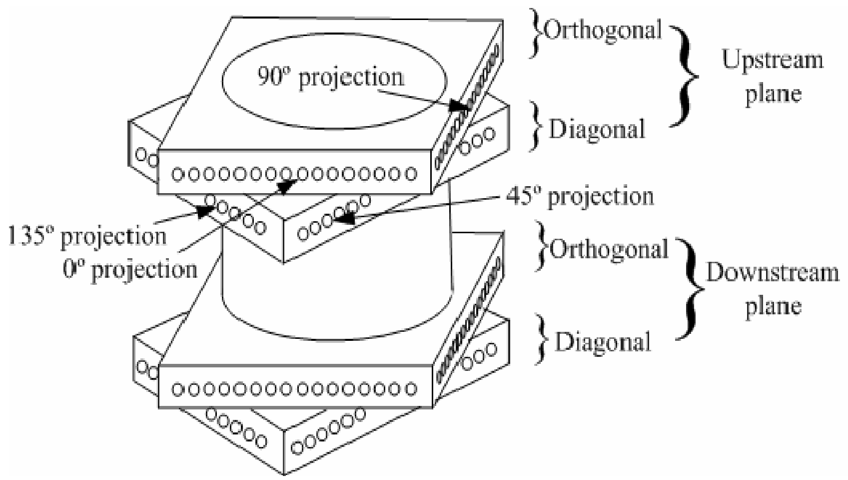

Figure 1 The arrangement of fiber optic holes for each projection

The upstream sensing array and the downstream array is placed 0.1 meter apart. Each part (downstream/upstream) consists of a combination of two orthogonal (0°, 90°) and diagonal (45°, 135°) projections. The diagonal projections were arranged in a similar manner to the orthogonal projections. The light emitted and received from the sensors using fiber optic [8] was collimated using 1.5 mm diameter holes, as shown in Figure 2

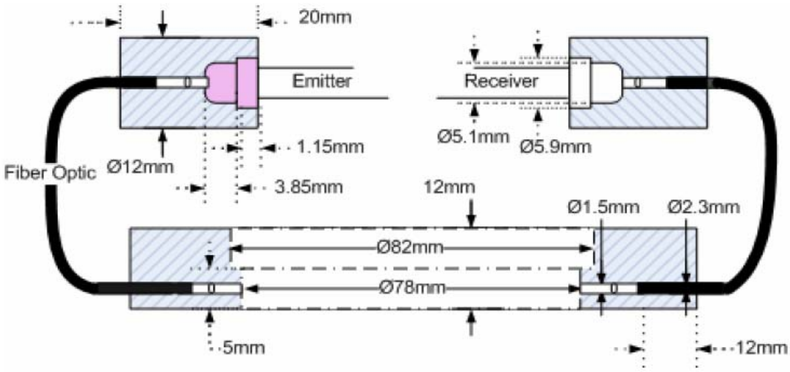

Figure 2 The fixture cross section rear view

The infra-red tomography system can be subdivided into three main parts: sensor configuration, signal conditioning, a data acquisition system and a personal computer (Figure 3). As a whole, a digital timing controller controls the system operation.

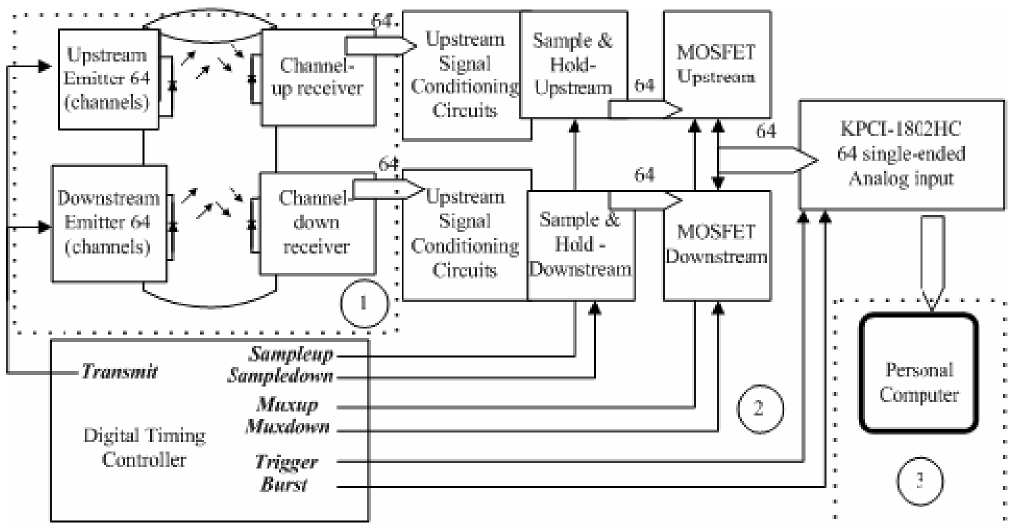

Figure 3 A block diagram of the infra-red tomography system

The sensor system is at the heart of any tomographic technique. The Siemens SFH4510 infra-red emitter and the SFH2510 infra-red receiver are selected as they are relatively cheap and have a fast response time. The infra-red emitters and receivers are connected to the measurement section via optical fibers.

The peak voltages received by photodiodes are equal to a level of infra-red light intensities and consequently relative to the two different components (solid and air) in the process/pipe traversed by the infra-red beam through an optical fiber. The analog signal is processed by a signal conditioning circuit. Finally, this analog signal is converted into a digital signal by the data acquisition system prior to entering a PC for processing it either off-line or on-line using image reconstruction algorithm. The algorithm is programmed using the Visual C++ software to provide the concentration profile.

3.0 MATHEMATICAL MODELING

The mathematical modeling made use of line integrals and projections representing the optical beams. Line integrals and projections are illustrated by employing the coordinate systems depicted in Figure 4. The line integral represents the integral of several parameters along a line. The object is represented by a two-dimensional function f(x, y) and each line integral is represented by the projection angle Ø and a detector position x' parameters [4].

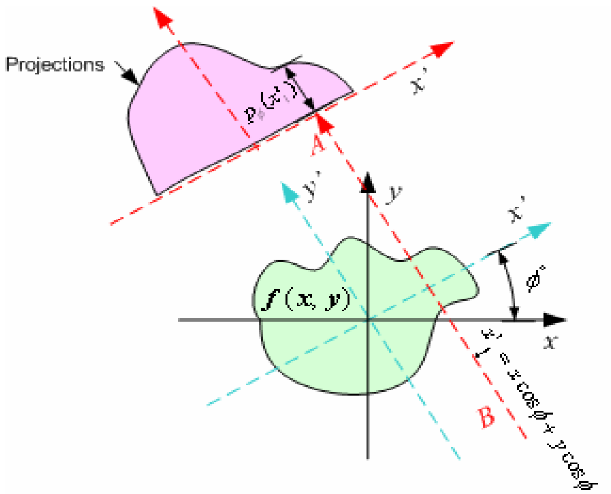

Figure 4 An object $f(x, y)$ and its projection $p_\phi(x_1')$, shown for angle ϕ°

The equation of AB in Figure 4 is

$$x\cos\phi + y\sin\phi = x' \qquad [1]$$

Where:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad [2]$$

In addition, this resulted in the following line integral

$$p_\phi(x') = \int_{(\phi,x')line} f(x,y)ds. \qquad [3]$$

$p_\phi(x_1')$ = projection data for AB line.

x_1' = the coordinate of AB line in x' plane.

The projection data can be written in discrete form as [9]:

$$p_\phi(x') = \sum_{y'} (f(x'\cos\phi - y'\sin\phi, x'\sin\phi + y'\cos\phi))\Delta y' \qquad [4]$$

4.0 EXPERIMENTS AND RESULTS

The experiments made use of an array of 64 upstream and 64 downstream infra-red sensors in real time by taking output voltage readings. The sensor reading were taken from voltage attenuation that comes from plastic bead flow which was dropped into a flow rig at various flow rates in range of 27 gs^{-1} to 126 gs^{-1}.

Combined Filtered Linear Back Projection ($CFLBP_{i+s}$) and Hybrid Linear Back Projection (HLBP) algorithm both at 32 × 32 pixels resolution were selected based on the discussion of quantity and quality measurements. Figure 4 shows the concentration profiles that represent the upstream and downstream selected samples of reconstructed flow images using the $CFLBP_{i+s}$ and HLBP algorithms at flow rate of 27gs^{-1} for half flow regime. The HLBP algorithm produced a clearer visual image compared to the $CFLBP_{i+s}$ resulting from the two phase "solid-air" flows that were forced to converge at the left-hand side of the distribution pipe.

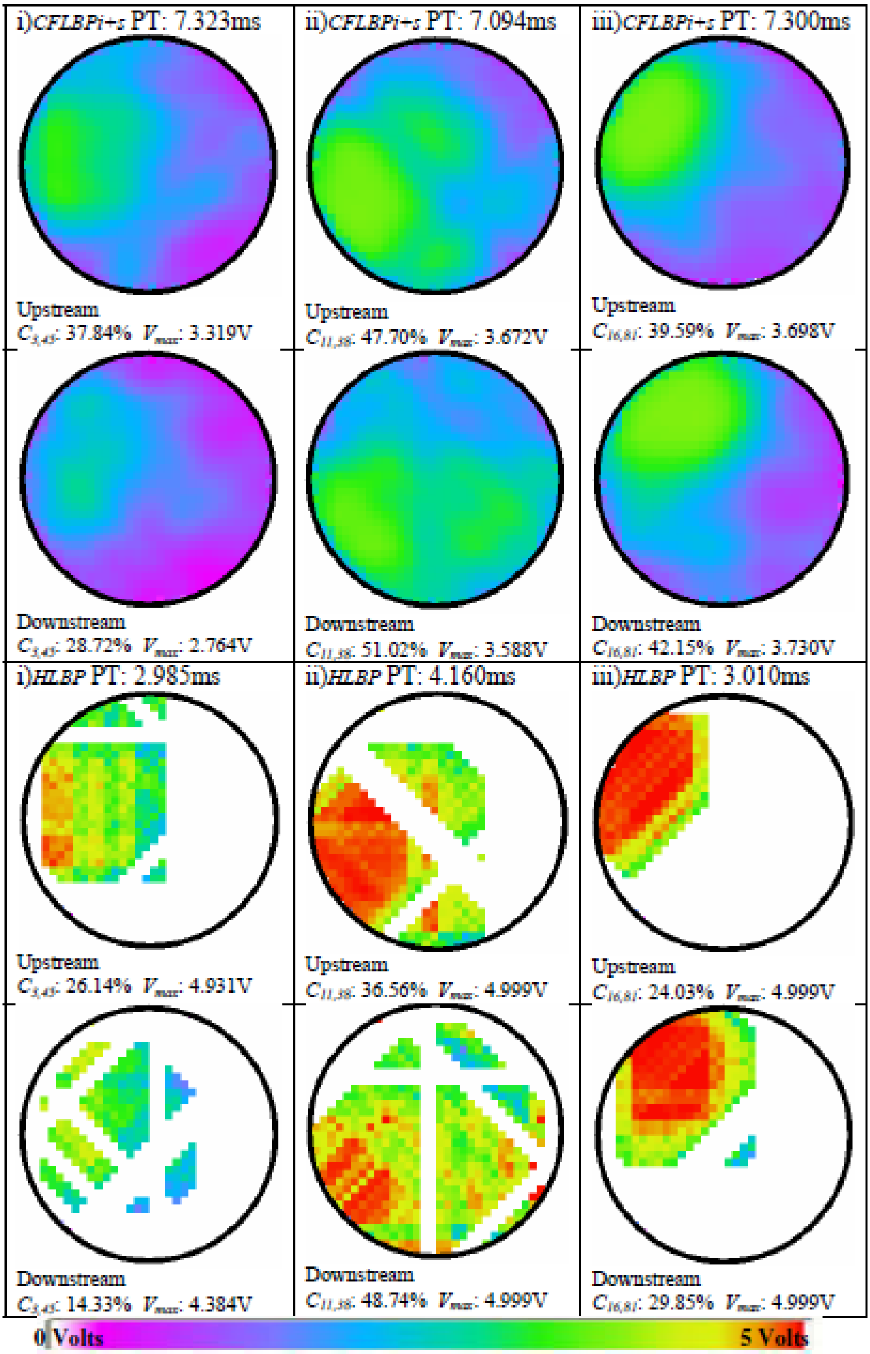

Figure 4 Concentration profiles for half flow at a flow rate of 27 gs-1 (CFLBPi+s and HLBP) (i) Cycle=3, buffer=45, (ii) Cycle =11, buffer=38, (iii) Cycle = 16, buffer =38, and PT = Processing Time.

5.0 CONCLUSION

An optical tomography system using infra red sensors has been developed and successfully tested. The experiments enabled the on-line testing of the effectiveness of the infra-red imaging system in visualizing the two-phase solid-gas flow in a flow rig model. The $CFLBP_{i+s}$ and HLBP algorithms both at 32 × 32 pixels resolution have been shown to be the most suitable image reconstruction algorithms based on the qualitative and quantative measurements with preference to the HLBP algorithm. For further work, more experiments and measurements with use of artificial intelligence such as neural network or fuzzy logic will be carried out in order to achieve image reconstruction or an auto-adjusting sampling rate system.

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