Flow Imaging in a Vertical Gravity Flow Rig using Optical Tomography

Sallehuddin Ibrahim
UniversitiTeknologi Malaysia, Malaysia

Mohd Amri Md Yunus
UniversitiTeknologi Malaysia, Malaysia

Mohd Taufiq Md Khairi
UniversitiTeknologi Malaysia, Malaysia

ABSTRACT
Process industries need a system that can image flow so that they can monitor the effectiveness of their process plant as well as detect any possible leakage or damages that might occur. This paper presents an optical tomography system which made use of infrared sensors to monitor the concentration profiles of solid flow in air conveyed by a vertical gravity flow rig. Several tests were conducted involving single pixel flow, multiple pixels flow, half flow and full flow. The results showed that the system is capable of providing vital information on the flow inside the rig in the form of concentration profiles.

Keywords
Tomography, Fiber Optics, Sensors

1. INTRODUCTION
Tomography is the combination of two words *i.e.*,tomo which means slice and graph which means picture. Flow imaging based on tomography provides a means of monitoring flow without interrupting the flow itself. This is because in tomography the sensors are placed around and near the object or flow of interest without touching the object or flow. Tomography has been widely used in the field of medicine in the form of x-ray system and has proved to be a powerful and effective system in providing useful information on the condition of patients. However for process, tomographic instrumentation has to be faster and robust. Optical tomography is an imaging system which is based on optical sensors that have the advantages of being straightforward and inexpensive [1].

Due to strong competition among the players in the process industries, there are strong demands for them to produce products economically and of high quality [2]. They also need state-of-the art technology which enable them to fulfill the market demand as well as comply with the regulation set by the government [3]. As such process industries must continuously monitor that the process plants are being operated smoothly and that any leakages are detected as early as possible. They also are trying to maximize profit, enhance quality and reduce wastages. This is where tomography can play a vital role. Data such as the concentration profiles of the flow obtained from tomography can be used to assess the quality of a process as well as utilized for design and control of processes.

This paper presents an investigation on the use of a tomography system which utilized optical sensors in the form of infrared sensors to visualize the flow of solid particles in a gravity flow rig. The optical tomography system is placed around the rig and data from the sensors are processed by suitable circuitry and data processing algorithm before being displayed on the computer.

2. MEASUREMENT SYSTEM
The infra-red tomographysystem (Figure 1) can be divided into four parts: sensor, signalconditioning, data acquisition system, and a computer. The circuit comprises four parts namely infra-red light projectioncircuit,signal conditioning for light reception, sample and hold circuit and digital timingcontroller. The infrared sensors which were used as transmitters and receivers were connected to the measurement section using fiber optics. Ibrahim et al.[2] has shown that the utilization of fiber optics can improve the resolution of the flow images when they conducted an investigation on a water column containing bubbles flowing in water. In order to get as much information as possible on the flow, a total of 64 sensors were installed around the pipe.The infra-red light projection circuit comprises a group of infra-red LEDtriggers which can produce a high current source and acts as a current variable foreach infra-red LED. The signal conditioning circuit change the signal received from the photodiode into a corresponding voltage. Output from the infrared sensors output are conveyed to signal conditioning circuits which filter and amplify the signals. The digitization process was performed on the analog signals a KPCI-1802HCdata acquisition boardhaving 64 channels. The overall system operation is controlled utilizing a PIC programmable controller. The signal is subsequentlyprocessed by the hybrid linear back projection algorithm before images were displayed on the computer.To reconstruct the concentration profile images, the pipe in the rig was mapped onto a map with a resolution of 32x32 pixels. The sensors were configured orthogonally and diagonally on top of each other so as to enable as much sensors as possible to be placed around the measurement section. There are 16x16 sensors for every orthogonal and diagonal projections.

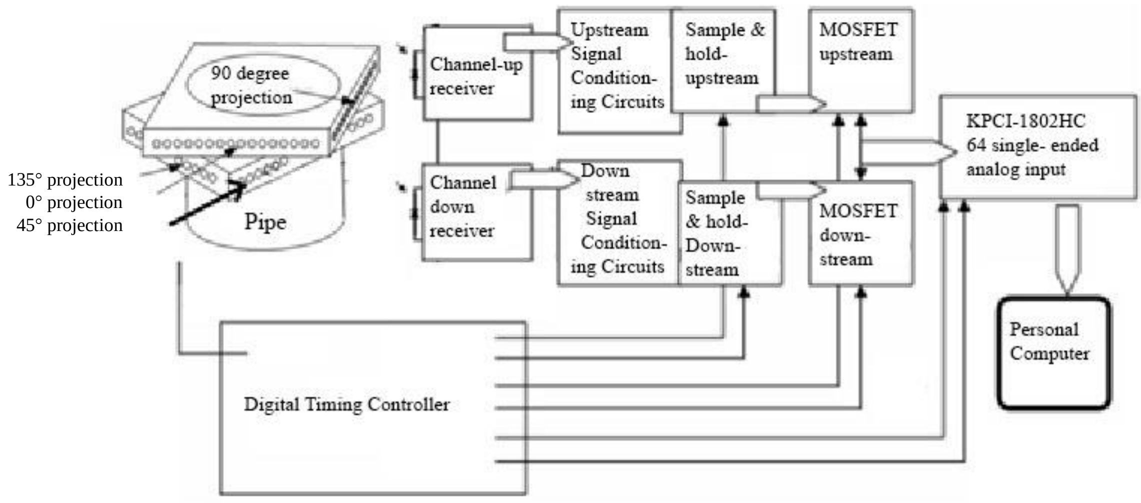

Fig 1: Tomography measurement system

Each infrared light transmitter and receiver was inserted into a specially-made rod in order tocollimate light and prevent the light transmitter/receiver from being exposedto external light such as lamp.Light from each receiver iscollimated by the rod towards the flow using fiber optic. Both ends offiber optic transmitter and receiver are configured to form lenses using heat from acandle light. The steps in forming the lenses is asfollows:

I. Carefully remove a section at the end of the fiber optic cladding using aknife, as shown in figure 2(a).
II. Ensure that 2 mm of the fiber optic is exposed without the cladding asin figure 2(b).
III. The end of the fiber optic is exposed to candle heat for several secondsuntil a convex surface is formed at the end of the fiber optic as infigure 2(c).

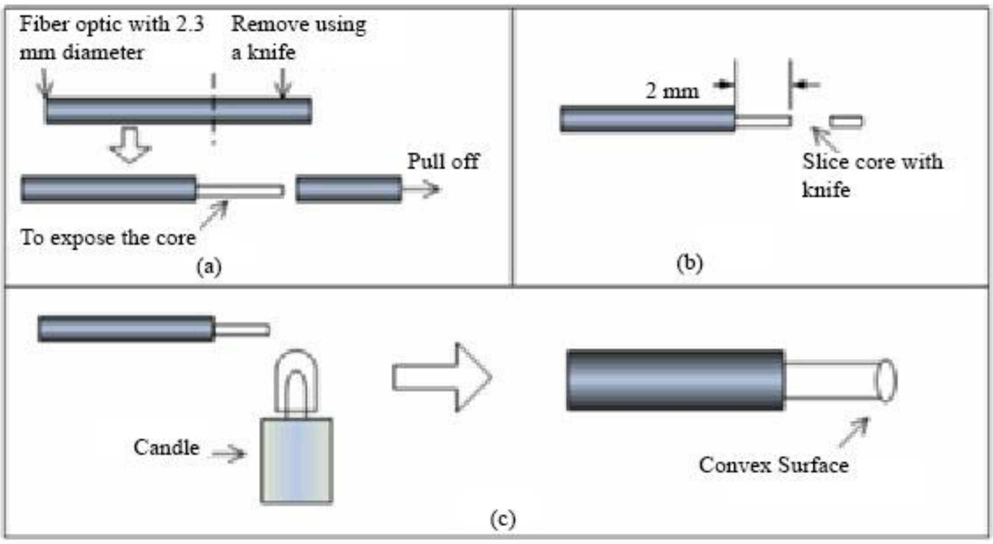

Fig 2: Preparation of fiber optic

The gravity flow rig is shown in figure 3. The rig contains a vertical pipe having an outer diameter of 0.082m and an inner diameter of 0.078m. Plastic beads each having a diameter of 3.3mm were dropped from the top of the rig. Anautomatic loader is utilized to convey the material from the tank via a vaneand will be stopped when the hopper is full. Then the beads weredropped from thehopper into the pipe via the measurement system. The flow rate ofthe beads was controlled by a rotary valve linked to an AC motor. The speedof the rotation is set by the control unit. A three-phase motor driver controlled the AC motor. This controller has 33programmable functions which can change the AC motor functions such as basefrequency, acceleration time, and torque boost.

Several experiments were conducted to test the capability of the system in measuring the concentration profiles of the beads. The tests involved four categories: Single pixel flow in the form of a static phantom having a diameter of 5mm, multiple pixels flow in which four objects placed at four different locations in the form of four static phantoms, half flow in which half of the rig is blocked and the beads were dropped in the other half of the rig and full flow in which the rig were fully opened and the beads were dropped as much as possible from the rig.

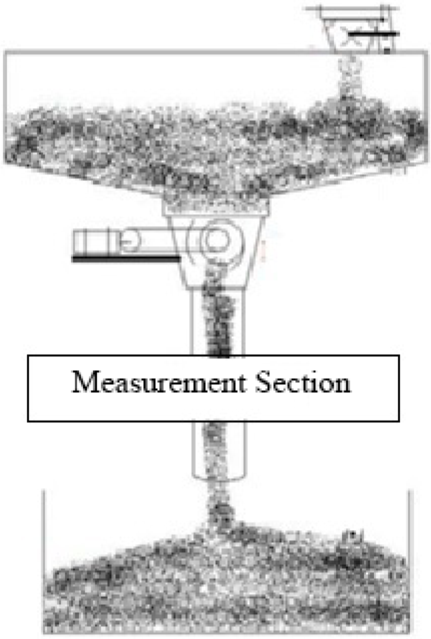

Fig 3: Gravity flow rig

In the single pixel case it is difficult to know the exact location where the bead was dropped if a bead was dropped randomly and as such a static phantom was used. Similarly in the case of the multiple pixels flow, four static phantom were used as it is difficult to drop four objects simultaneously and know the exact location of those objects.

In order to display the concentration profiles on the computer, the Hybrid Reconstruction (HR) algorithm was used [4]. This algorithm determines thecondition of projection data and enhanced the reconstruction by setting the empty area or the pixel where no object exist as zero when reconstructing the images. By doing this the smearing effect which is due to the limitation of the back projection technique is minimized. The projection data obtained by Ibrahim [5] is based onthe sensor value.Thehybrid reconstruction algorithm can be expressed mathematically as:

$$\hat{f}(x,y) = \sum_{m=0}^{M-1}\left[\sum_{n=0}^{N-1} Vs_{Tx,Rx}(x_n{}',\emptyset_m).\overline{S_{\emptyset_n(x,y)}}.B(x_n{}',\emptyset_n)\Delta x'\right]\Delta\emptyset \quad (1)$$

where,

$\hat{f}(x,y)$= an approximation of the objection function in volts

$Vs_{Tx,Rx}(x_n{}',\emptyset_n)$= amplitude of signal loss for receiver from transmitter to receiver view which is equal to the projection data

$\overline{S_{\emptyset_n(x,y)}}$= normalized sensitivity map for each projection

$B(x',\emptyset)$ = hybrid reconstruction algorithm constant value for each receiver

V_{Th}= threshold voltage

$\emptyset_m$= the m-thprojection angle

x_n' = receiver n^{th} position

$\Delta\emptyset$= angular distance between the projection and the summation comprising all the M-th projection

N= total number of receivers

M = total number of projections

3. RESULTS AND DISCUSSION

Figure 4 shows some of the results in the form of concentration profiles when the solid beads were dropped vertically downwards in the flow rig. The single pixel concentration profile was obtained when the phantom was in static condition. Similarly the multiple pixels concentration profile was obtained when the phantoms were placed in a static manner. In the case of the half flow, the experiment was conducted by closing half of the rig and the plastic beads were dropped in the half of the opening. In the case of the full flow the rig was fully opened and the plastic beads were allowed to drop freely from the top of the rig.

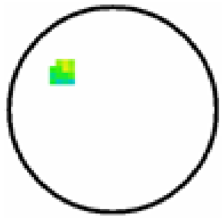

Fig 4: (a) Single pixel flow

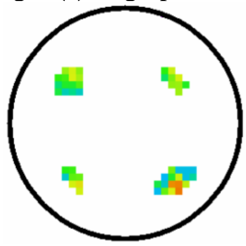

Fig 4: (b) Multiple pixels flow

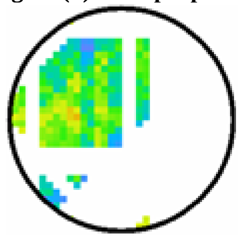

Fig 4: (c) Half flow at 93g/s

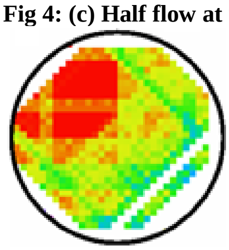

Fig 4:(d) Full flow at 93g/s

The concentration profile of the single pixel as in figure 4(a) represented a single circular rod placed in the rod which occupied four pixels when the resolution was set at 32x32 pixels. However due to the smearing effect caused by the limitation of the reconstruction algorithm, a few other pixels are also occupied. The multiple pixels flow shown in figure4(b) shows four different locations in the pipe being occupied representing four different solid circular rods placed at four different locations in the pipe. Noise caused slight smearing on the images. The concentration profile of the half flow in figure 4(c) at a flow rate of 93g/s shows that almost half of the pipe is occupied. It can be expected that when the solid beads are dropped from the top of the rig, the bead will flow downwards and some it will be slighly dispersed towards the other half of the pipe and some will hit the sides of the pipe. The full flow concentration profile image representing the flow rate at 93g/s in figure 4(d) shows a majority of the pipe is occupied. As the beads are dropped randomly from the top of the pipe, it cannot be expected that the image will show all pixels being occupied.

4. CONCLUSION

An optical tomography system employing infrared sensors have been developed and has been tested. Several tests conducted shows that it is capable of providing information on the concentration profile of static phantoms as well as dynamic flow. It is capable of accurately showing the location of the objects in the flow rig. The use of hybrid back projection algorithm has successfully minimized noise caused by the back projection algorithm. Further tests can be conducted on other types of flow as well as other phases involving liquid. **Tomography** seeks to help the scientific community by integrating the traditional narrowly focused "siloes" of imaging technologies in an effort to provide a low-resistance conduit bridging disciplines to promote integrated scientific advancements.

5. ACKNOWLEDGMENT

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6. REFERENCES

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