

Real-Time Visualising Image Of Flame By Laser Based Transmission Tomography

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Abstract - This paper deals with the development of flame imaging system using laser-based tomography. The aim of this project is to obtain the concentration profile of the flame to be incorporated in laser-based transmission tomography measurement system for combustion on-line monitoring. The system can be applied in real-time manner to produce a cross sectional images of flame such as that in a combustion chamber. The ability of this system is to monitor the size, position and velocity of flame fronts in any combustion behavior and emissions. The system employs two orthogonal projections with one laser source. The concentration of the research is to determine the position and velocity of flame fronts in the pipeline by employing photodiode sensor and Helium Neon Laser. The flame is placed in specific places in the measurement cross section and voltage output will be calculated by the individual sensor is modeled.

Keywords: laser-based transmission tomography, photodiode, flame, linear back projection, image reconstruction.

1 Introduction

Process tomography provides several real-time methods of viewing the cross-section of a process to provide information relating to the material distribution. This involves by taking numerous measurements from sensors which are placed around the section of the process being investigated and processing the data to reconstruct an image. The process involves the use of non-invasive sensors to acquire vital information in order to produce two or three dimensional images of the dynamic internal characteristics of the process system. Information on the flow regime, vector velocity, and concentration distribution may be determined from the images. Such information can assist in the design of process equipment, verification of existing computational modeling and simulation techniques, or to assist in process control and monitoring.

Process tomography refers to any tomographic method used to measure the internal state of a chemical

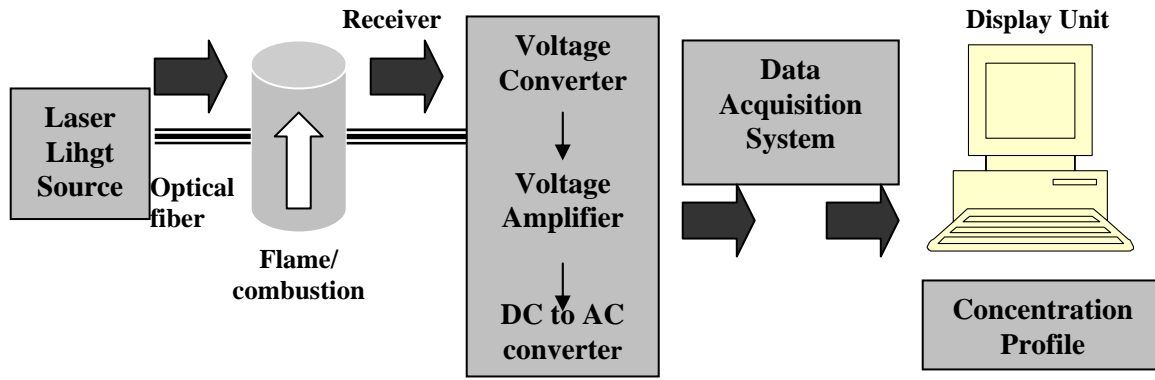
process (e.g. material distribution in a reactor, multiphase flow fields in piping or concentration uniformity in mixers). By tomographic techniques can measure quantities such as the flow rate or solid concentration of material flowing through a pipeline and the distribution of material inside a chemical reactor or a mixer. This type of information is not usually obtainable with the sensor traditionally used by engineers, therefore these techniques give a better understanding of the flow of material through the plant and the data can be used to design better process equipment and to control certain processes to maximize yield and quality.

Basically, in a tomography system several sensors are installed around the pipe or vessel to be imaged. The sensor output signals depend on the position of the component boundaries within their sensing zones. A computer is used to reconstruct a tomographic image of the cross section being interrogated by the sensors. Real-time images can be obtained which measure the dynamic evolution of the parameters being detected at the sensors.

This paper will describe how to reconstruct the image of the internal flows in the pipeline and display it online as the concentration profile over a cross section by using photodiode as sensors. In this project a narrow laser light is emitted through the cross-section area of the pipe to a receiver, by using a fiber optic as transmitter and photodiode as a receiver then the amplitude of the received light is compared with the amplitude of light that achieved with no obstruction in the light path for the same sensor. The intensity of the transmitted beam is measured by the detector and the transmittance is the ratio of the transmitted intensity to the original beam intensity. The ratio of light attenuated will be used to construct the cross-section image in the pipe. The resolution of such a system is limited by the physical number of the components used as light transmitter and receiver.

2 The Measurement System

The system is being split into several parts. Figure 1 shows how the systems work out from the source until the



Signal conditioning circuit

Figure 1 : Block diagram of Process tomography system

final concentration. The photodiode is being used to detect the laser light through the optical fiber. The laser light was collimated by a lens before its passes through the optical fiber. The photo-detector will generate an electrical current within a range of micro Amperes that propagates to the intensity of the received light, then the current is being fed into electronic device to perform signal measurement. Nevertheless, the output signal is dependent on the position of the component boundaries within their sensing zone. The measured data are then being transferred to a computer through a computer data acquisition system. Computer software is being used to obtain the concentration profile regarding to the flow.

The source will supply 12 light beams, this result in the cross section of the pipe being interrogated by a total of 12 beams. When the flame passes through the bottom of the pipelines, twelve sensors are mounted around the periphery at the middle of the pipelines will detect the flame. The twelve sensors are connected to the analogue sensing electronics (signal conditioning circuit to convert the information into an electrical signal) and then digitized (data acquisition system in order to convert the signal into computer codes) before its being reconstructed and visualized.

The display unit, data acquisition system (DAS) that will used in this case study is the Keithly DAS1802HC. It can be configured for 64 single ended or 32 differential, 12 bit input and can measure up to 333K samples/s maximum input rate. The DAS is responsible to obtain the quantitative data describing the internal flow pipeline. By using DAS data has to be collected quickly and accurately in order to track small changes of flows in real time thus enabling the reconstruction algorithm to provide and accurate indication of true flow distribution before it display the concentration of the image.

This system is design based on the ability of the transmitter and receptions of the sensors used, by using transmission mode method. In completing this research, the works to be carried out including: mounting 12 optical sensors on the outer surface of the 60mm transparent pipe, designing the receiver circuit, and developing the online image reconstruction by using software, Visual C++.

The principle of this system is investigates the light attenuation level, thus the measurement that has been selected is measurement based on light attenuation intensity. To simplify the construction, DC constant source are used.

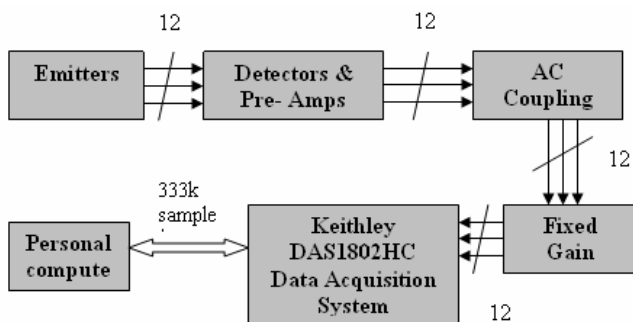


Figure 2: Function block Diagram of the system design

The photodiodes are configured in photovoltaic mode (voltage-output operating mode) and a second current to voltage converter resistor is added to the photodiode output and non-inverting input of the op-amp. This configuration results a differential-input current to voltage converter, which provides a better solution to noise sensitivity and DC offset error. Figure 2 shows corresponding pre-amp circuit. The circuit is operated in parallel mode where each sensor will provided with its own pre-amp and amplifier system. A variable resistor include in each set of amplifier to provided an adjustable gain.

The Laser light will emit light continuously, so the output from the electronics circuits are 12 voltages

proportional to the intensity of light arrived at the corresponding receiver. Any obstacle that crosses the light will decrease the signal output of the corresponding light paths detector. A preamp is used over each detector to convert the photodiode current to voltage and an adjustable gain amplifier is used to interface the voltage to analog input of a data acquisition system (DAS). Through the DAS, signal produced by the photodiode are available for image processing using computer programming.

As a system develop based on transmission tomography that employs two orthogonal projection, the fibers and sensor are mounted into the 24 holes in the block projection which its tight to the rod and each projection provides six light beams and six detector which are parallel and equally spaced to each other. The Bunsen burner are placed at the bottom the pipelines. Figure 3 shows the system development.

3 Image Reconstruction

In constructing the image of interest, the cross sectional of the image is obtained from projections. The Linear Back Projection method is chosen for this system in order to perform the concentration profile of the cross-sectional image of flame. The system developed based on transmission tomography that employs two orthogonal projections. Each projection provides six light beams which are parallel and equally with a photodiode.

The laser emitters and detectors are arranged on a one-to-one basis. For the two orthogonal projections, the projection angle is arranged in 0° and 90° . The object position is represented by a two dimensional function $f(x,y)$ and each line integral is represented by the detector position x' parameter, (ϕ, x') . The coordinate system $f(x,y)$ illustrated in figure 4 is used to describe line integrals and projections. The percentage of total concentration, C is based on the following equation;

$$C = \frac{\left(\sum_{y=0}^{n-1} \sum_{x=0}^{n-1} V(x, y) \right)}{Pixels_{sum}} \times 100 \quad (1)$$

$V(x, y)$ = The obtained concentration profile with resolution of $n \times n$ pixels for modeled image or reconstructed image.

$Pixels_{sum}$ = The total of pixels occupied by any light beam. Determined by counting the number of elements in total sensitivity matrix that possesses a non-zero value.

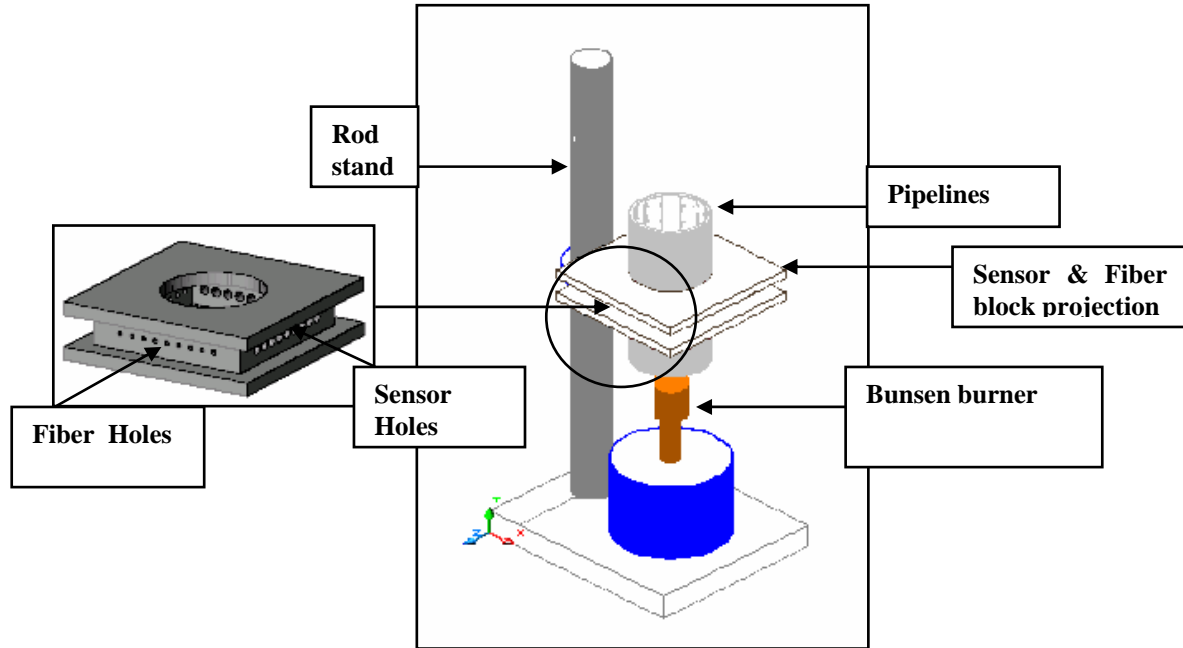


Figure 3: Hardware Development

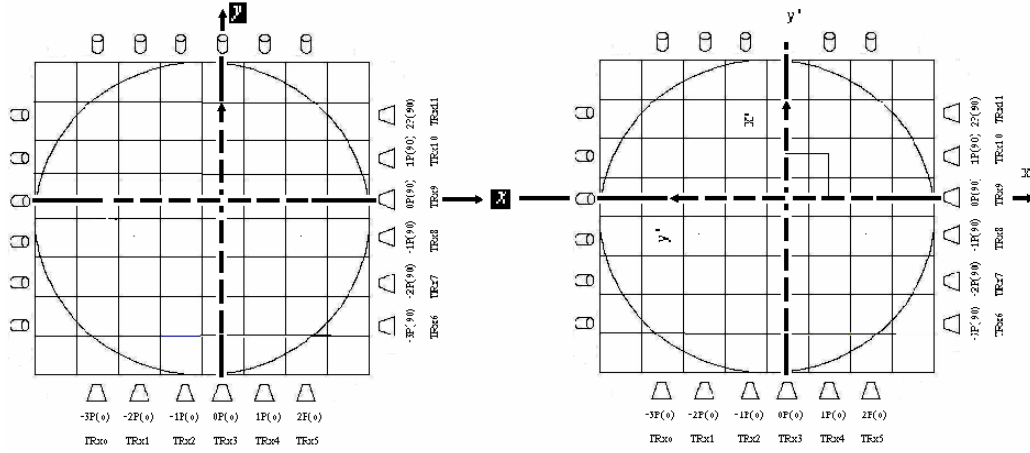


Figure 4: The two dimensional function $f(x,y)$ is arranged into two orthogonal projections $P_\phi(x')$ is shown for angle ϕ , 0° and 90°

The equation for receiver (detector) position can be defined as ;

$$x' = x \cos \phi + y \sin \phi \quad (2)$$

where:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos \phi & \sin \phi \\ -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \quad (3)$$

and this result in the relationship line integral $P_\phi(x')$:

$$P_\phi(x') = \int_{(\phi, x') \text{ line}} f(x, y) ds \quad (4)$$

By using delta function, this can be written as:

$$P_\phi(x') = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) \delta(x \cos \phi + y \sin \phi - x') dx dy \quad (5)$$

For discrete implementation, Equation 5 can be rewritten ;

$$P_\phi(x') = \sum_{M=1}^{M-1} \left[\sum_{N=0}^{N-1} f(x, y) \delta(x \cos \phi + y \sin \phi \Delta x) \Delta y \right] \Delta x \quad (6)$$

Where;

P_ϕ =projection angle,

x' =detector position in x plane

$f(x,y)$ =coordinate(position) of real object,

N=total num of receiver

M=total num of projections

The reconstructed image, depending on the physical sensing system, may contain information on the cross-sectional distribution of the constituent parameter of the object. The important steps towards in image reconstruction where the projection data $P_\phi(x')$ is the sum of line integral of the normal straight line paths (Hoyle *et al.*, 1995).The projection data $P_\phi(x')$ will be the base data for reconstruct the image reconstruction.

The reconstruction may involves transform method, for example the Fourier transform is used in represent an image as a sum complex exponentials of varying magnitudes, frequencies and phase. By trying to invert the line integral in equation 5, an intuitive approach become available to reconstruct an approximate of the object function in volts, $\hat{f}(x, y)$ of the object function $f(x, y)$.The equation can be written as follows;

$$\hat{f}(x, y) = \int_0^{+\infty} \int_{-\infty}^{\pi} P_\phi(x') \delta(x \cos \phi + y \sin \phi - x') dx' d\phi \quad (7)$$

For given point (x,y) of the image plane, and for a direction of the projection ϕ , a projection value is correspond to $x' = x \cos \phi + y \sin \phi$ as expressed in equation1. For all projection, the contributions to the point (x,y) are summed. This mechanism is called back projection and also can called as the summation method. Now the discrete back projection can be written as ;

$$\hat{f}(x, y) = \sum_{m=0}^{M-1} \left[\sum_{n=0}^{N-1} V_{x,R,x'}(x', \phi) \delta(x \cos \phi + y \sin \phi - x') \times \overline{S_\phi(x, y)} \Delta x' \right] \Delta \phi \quad (8)$$

Where ;

$\hat{f}(x, y)$ = approximation of the object functions in volt

$V_{S_{Tx,Rx}}(x', \phi)$ = amplitude of signal loss of receiver from Tx to Rx view that is equal to projection data

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

ϕ = the projection angle

$\Delta\phi$ = receiver position

x' = angular distance between projection and the summation extends over all the M-th projection

N = total number of receiver

M = total number of projection

4 Result

The implementation of the described algorithms are performed by using Microsoft Visual C++ programming language and processed in 9 bits digitalization scale. The original output from each type of reconstruction is a set of numerical result, namely concentration matrix. 511 types of colours are used to perform a gradient colours scale which represent the numerical scale in concentration matrix. By using this technique, the concentration matrix is converted to image. The percentage of total concentration provides information regarding the density of objects distribution in the image plane. Figure 5 and figure 6 shows the result of repeatable variation of reconstructed image of flame with the flame position in different open volume, where the gas flow rate of the Bunsen burner are varied in half opened and fully opened.

5 Conclusions

The ability of this system to visualize the characteristic of the flame provides the possibility of this system to be implemented such as in combustion chamber. The concentration measurement has been successfully displayed by the system. This will prove that as the light travels across the combustion volume, a true cross-sectional view of flame can be reconstructed. The system is able to locate the flame position and flame size. By that measurement of the flame failure can be identified. The mathematical modeling for sensors output and image reconstruction algorithm has been derived and integrated in software development. By viewing the image reconstruction algorithm of the flame imaging the two-dimensional cross-sectional of the distribution of permittivity in the slice can be obtained, by that the combustion phenomena can be characterized.

6 References

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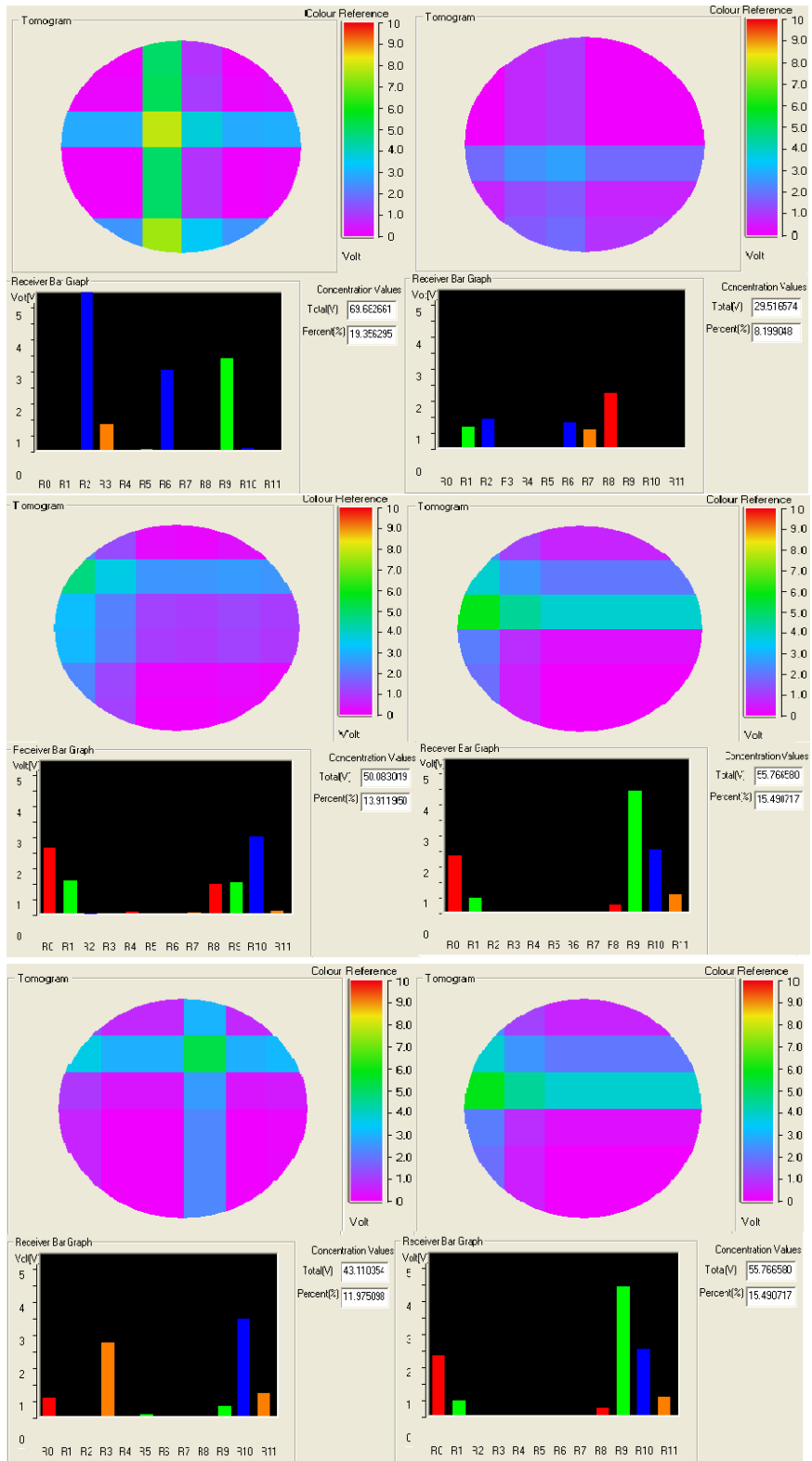


Figure 5: Variation of reconstructed image of flame when the burner was half opened

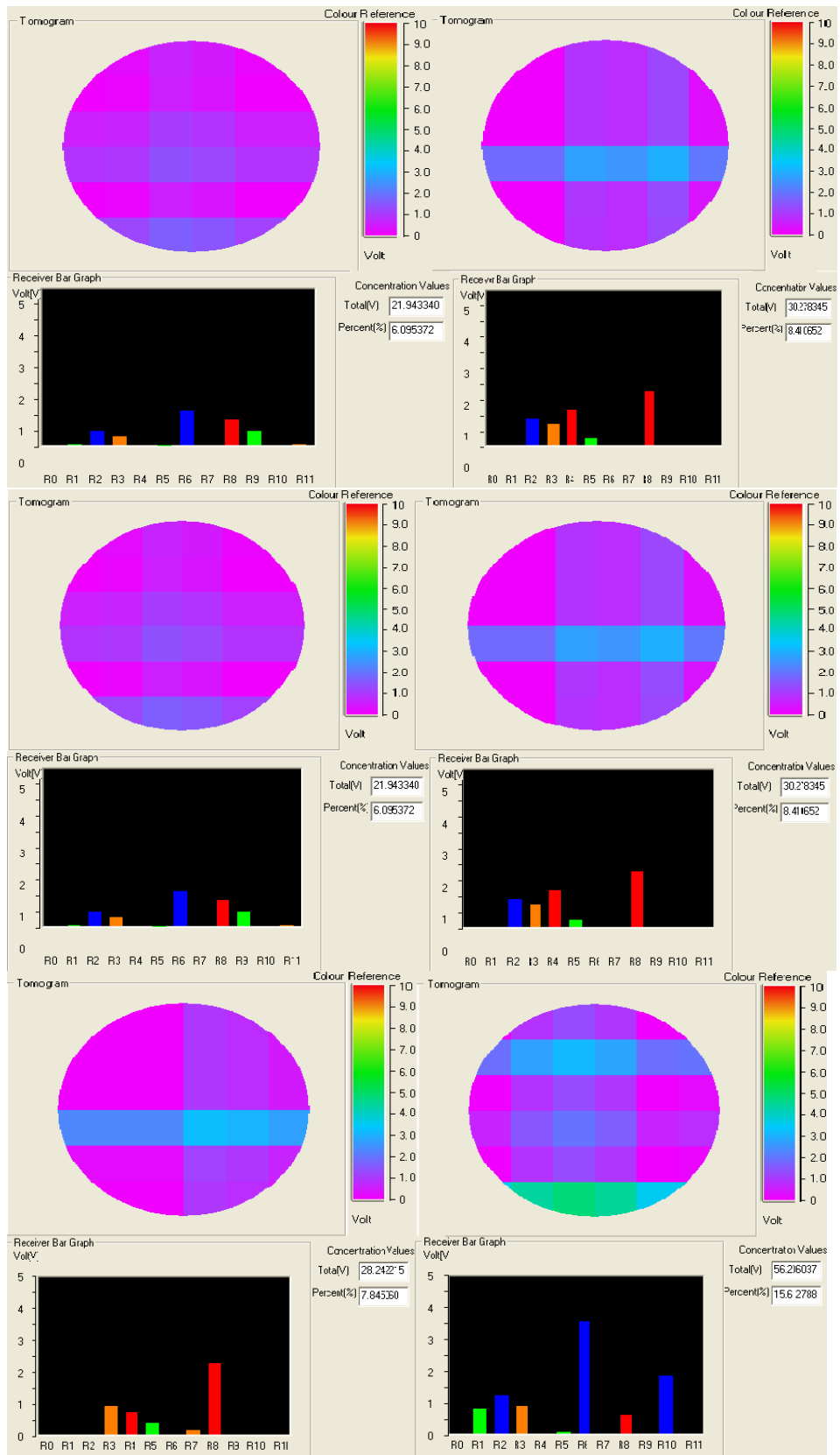


Figure 6 : Variation of reconstructed image of flame when the burner was fully