The 14th International Conference on Fluidization – From Fundamentals to Products

Refereed Proceedings

2013

Development of a High Temperature Endoscopic-Laser PIV/DIA Technique for the Study of Hydrodynamics of Gas-Solid Fluidized Beds

I. Campos Velarde
Eindhoven University of Technology, Netherlands

L.J. van Heck
Eindhoven University of Technology, Netherlands

F. Gallucci
Eindhoven University of Technology, Netherlands

M. van Sint Annaland
Eindhoven University of Technology, Netherlands

Recommended Citation

I. Campos Velarde, L.J. van Heck, F. Gallucci, and M. van Sint Annaland, "Development of a High Temperature Endoscopic-Laser PIV/DIA Technique for the Study of Hydrodynamics of Gas-Solid Fluidized Beds" in "The 14th International Conference on Fluidization – From Fundamentals to Products", J.A.M. Kuipers, Eindhoven University of Technology R.F. Mudde, Delft University of Technology J.R. van Ommen, Delft University of Technology N.G. Deen, Eindhoven University of Technology Eds, ECI Symposium Series, (2013). http://dc.engconfintl.org/fluidization_xiv/45

DEVELOPMENT OF A HIGH TEMPERATURE ENDOSCOPIC-LASER PIV/DIA TECHNIQUE FOR THE STUDY OF HYDRODYNAMICS OF GAS-SOLID FLUIDIZED BEDS

I. Campos Velarde*, L.J. van Heck, F. Gallucci, M. van Sint Annaland
Eindhoven University of Technology; Dept. Chemical Engineering and Chemistry
PO Box 513, 5600 MB Eindhoven, The Netherlands
*T: +31-40-247-3685; F: +31-40-247-5833; E: i.camposvelarde@tue.nl

ABSTRACT

In the present work, the development of a novel non-invasive experimental technique based on endoscopic-laser Particle Image Velocimetry (ePIV) coupled with Digital Image Analysis (DIA) is presented. The technique has been validated at room temperature with a cold flow setup and conventional PIV-DIA, proving that no loss of resolution and accuracy is affecting the new technique. An experimental set up has been designed and constructed to apply the technique up to 1000ºC.

INTRODUCTION

Bubbling fluidized bed reactors have been used in the chemical industry for long time. Industrial fluidized bed reactors are often operated at temperatures as high as 1000ºC. To design these reactors, phenomenological reactor models for gas-solid fluidized bed reactors have been developed, that rely heavily on constitutive equations for the fluid dynamic characteristics (e.g. equivalent bubble size and bubble rise velocity). These correlations have only been obtained and validated for fluidized beds operated at low temperatures. In order to improve both reactor design and operation a better understanding of the prevailing phenomena occurring at higher temperatures is required.

Different studies on fluidized bed reactors at room temperature have been carried out in the past years with both invasive and non-invasive experimental techniques. The non-invasive technique Particle Image Velocimetry (PIV) coupled with Digital Image Analysis (DIA) provides a whole field measurement, while simultaneously delivering both bubble phase properties and solids circulation patterns of fluidized beds with high temporal and spatial resolution (1,2). Due to the required visual access, PIV/DIA can only be applied to pseudo 2D fluidized beds. Simulations with a Discrete Particle Model (DPM) are the bridge between pseudo 2D and 3D fluidized beds.

In this works, for the first time the combination of PIV/DIA has been further extended to high temperature fluidization and has been used to study the hydrodynamics of bubbling fluidized beds at temperatures up to 1000ºC. This is made possible with the aid of high temperature endoscopes. This kind of endoscope has been generally used to inspect high temperature environments such as glass furnaces or combustion chambers, and also been applied for PIV measurements of gas flowing in combustions chambers. Rottier et al. (3) coupled a high temperature endoscope with a PIV CCD camera. They applied endoscopic PIV on a laboratory-scale furnace operating in the flameless mild combustion regime. The velocity field was obtained by seeding methane and air with zirconium dioxide particles.

In the present study, firstly, the novel ePIV/DIA using both optical and laser high temperature endoscopes is validated at room temperature with comparison with standard PIV/DIA measurements. This is done by comparing the hydrodynamic parameters obtained with the endoscopic-laser PIV/DIA with the standard PIV/DIA illuminated with LED lights and using standard camera lenses; which is set as benchmark. Then, the design of the endoscopic-laser PIV/DIA high temperature setup is described.

EXPERIMENTAL PART

This section explains briefly the non-invasive techniques Particle Image Velocimetry (PIV) and Digital Image Analysis. It also describes how the technique was extended to high temperature applications, and the lab set up design for the implementation of the technique.

PIV/DIA technique

PIV is a non-intrusive technique used for whole field measurement of solid circulation patterns and solids velocities in gas-solid fluidized beds. A high speed camera takes consecutive images of the fluidized bed with an inter frame time between 1-3 ms. Every image is divided in small interrogation areas (128x128 pixels). In every interrogation area, cross correlation is carried out on a pair of consecutive images to obtain the most probable displacement of the particles, making possible to reconstruct the solids velocity field in the whole bed. In this work, these PIV image pairs are post-processed using the commercial software package DaVis. A multi-pass algorithm using interrogation areas of 128x128 and 64x64 pixels, respectively, is employed to reconstruct the corresponding solid velocity field.

Digital Image Analysis (DIA) is an image post-processing algorithm. It works by discriminating bubble and solids phase based on the pixel intensity. Afterwards a correlation is used to convert pixel intensity to bed porosity; the correlation used in this work was obtained based on DPM simulations [4]. As a result, bubbles can be tracked, obtaining time averaged bubble characteristics (rise velocity, diameter, number of bubbles, etc).

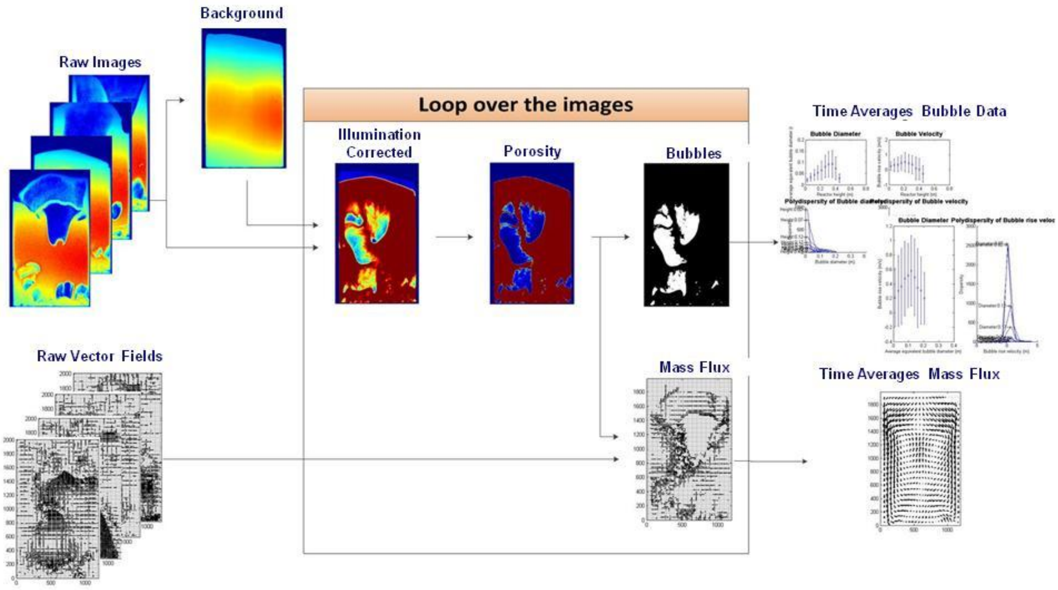

Figure 1. Flow diagram for PIV/DIA

Finally, the combination of the porosity plots and time averaged vector plots are combined to obtained the time average mass fluxes in a fluidized bed, as illustrated in figure 1.

Development of the novel ePIV/DIA

A typical set up to run PIV/DIA at room temperature consist of a high speed camera placed in front a pseudo 2D fluidized bed. The required illumination is obtained form a set of LED lights (Figure 2).

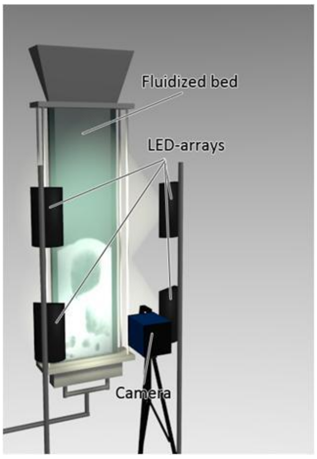

Figure 2. Schematic drawing of standard PIV/DIA set up

The first step to extend this technique to high temperature is to find the right heating mechanism. Due to the high heat losses of the transparent pseudo 2D bed, the only way to supply homogeneous heating is to place the column inside a furnace. As a consequence, the high speed camera has to stay out of the furnace. First trail was to have visual access to the furnace through a glass window, but this makes difficult to capture the whole bed, while heat losses though the window are also large creating a risk for the camera. Therefore, the possibility to use a high temperature endoscope was explored. High temperature endoscopes typically are used for inspection of glass furnaces and can thus work at very high temperatures (> 1000°C).

The first attempt to run endoscopic PIV/DIA was done by coupling the high speed camera with the high temperature endoscope at room temperature. The illumination was provided by LED lights. To acquire images, the exposure time was increased 20 times and the inter frame time five times more than in a standard PIV/DIA experiment. Figure 3 shows the comparison of a standard PIV/DIA (no endoscope) and the endoscopic PIV/DIA. In the standard case, PIV can track particles and obtain the vector for particle displacement. Due to lack of illumination, PIV failed to track particles In the case of endoscope and LED lights,. It was estimated that at least 8 times more light was required to overcome the illumination loss due to the use of the endoscope. An endoscope with a larger tip-lens was tested. Increasing two times the size of the tip-lens, decreases by four the required light.

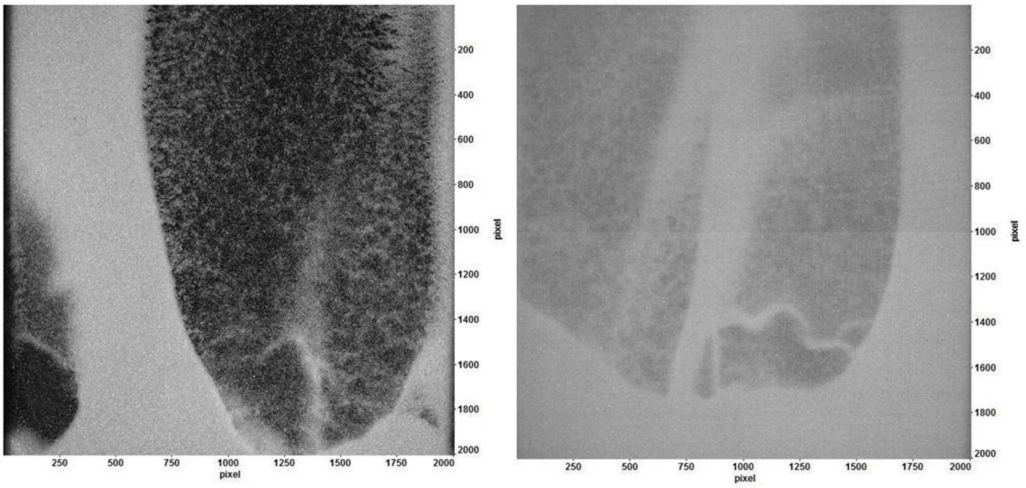

Figure 3. Standard PIV/DIA (left), with endoscope (right)

In order to fill the lack of illumination, a double pulse Nd:Yag laser (SOLO IV 50mJ/pulse) was tested. This kind of laser has already found its application in PIV for gas-liquid applications. For instance, it has been applied to spray driers, and bubble columns to determine the flow field. The main challenge to apply a double pulse laser to illuminate a pseudo 2D fluidized column is the area of interest. The laser has to illuminate the surface of the pseudo 2D fluidized bed instead of a cross-section; therefore instead of a laser-sheet, a laser-cone is required for illumination. Additionally, an inherent property of the pumped Nd:YAG lasers is the presence of pulse to pulse difference in coherency. When the beam subsequently passes through the lenses this difference is enhanced. In order to tackle the issues caused by the use of a double pulse Nd:Yag laser, a homogenizer was developed by the Bayerisches Laserzentrum to remove the pulse to pulse differences and to diverge the laser light into a cone. The laser beam is divided into beamlets by two micro-lenses arrays. The beamlets are overlapped with help of plan-convex lens in a plane behind this lens. To supply illumination inside the furnace, the double pulse laser was coupled also to a customized high temperature endoscope.

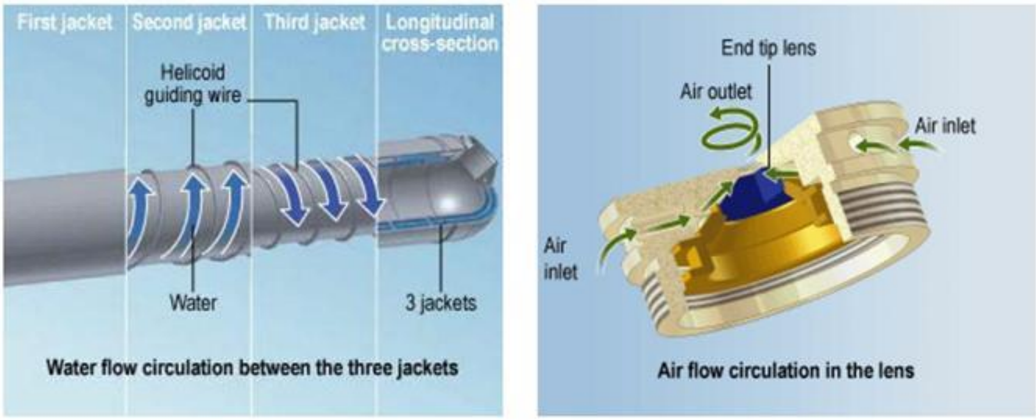

Figure 4. High temperature endoscope

The high temperature endoscope used in this work is the 38 mm double jacket manufactured by Cesyco Kinoptic Endoscopy. This endoscope has a water-cooled jackets and an air-cooled end tip-lens, making possible to use it up to 1000°C. A sketch of these cooling features is displayed in Figure 4. In addition, OptoPrecision developed a customized high temperature endoscope to use the homogenizer and to couple it with the laser.

RESULTS AND DISCUSSION

This section covers firstly the validation of the technique at room temperature. Then it is presented the configuration of the new set up for high temperature ePIV/DIA.

Validation of the technique at room temperature

The first step to extend PIV/DIA to high temperature is to validate the use of the optical and laser endoscope. A series of experiments at room temperature were carried out to characterize the influence of the optical and laser endoscope in PIV/DIA measurements.

The standard PIV/DIA is set as the benchmark. The optical high temperature endoscope was coupled with a high speed camera and the Nd:Yag laser was couple to the high temperature laser endoscope. The laser was place at the right side of the column. For both cases, glass beads of 500 µm were fluidized by air in a pseudo 2D bed (0.25 x 0.9 x 0.015 m).

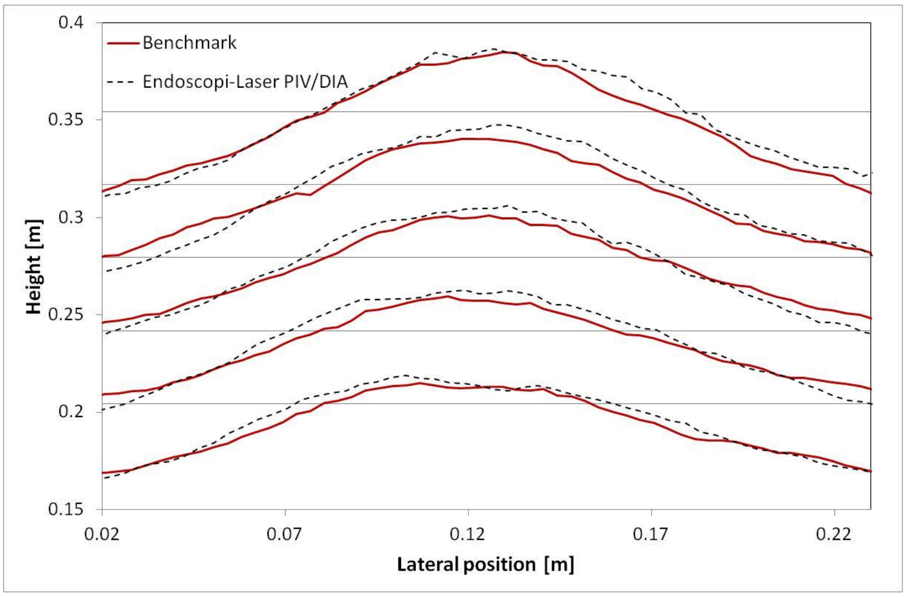

Figure 5 Lateral solids profiles at room temperature.

The results of the validation of the endoscopic-laser PIV/DIA is presented in figure 5. The solids profiles of the ePIV/DIA follow the same trend as the benchmark. The deviation of the solids fluxes estimated with the ePIV/DIA is within the 10% of deviation of the standard PIV/DIA [5]. The major variation is due to the difference in illumination. The endoscopic-laser PIV/DIA has a single source of illumination, while four LED lights provide the illumination in the standard PIV/DIA. There is good agreement between the two cases, proving that it is possible to run PIV/DIA measurements using the optical endoscope and the illumination provided by the Nd:Yag laser.

Lab Setup

In figure 6 a schematic representation of the set up for high temperature ePIV/DIA measurements is shown. The pseudo 2D fluidized bed is placed inside the furnace, it has to be transparent to assure the visual access and withstand temperatures up to 1000C. A pseudo 2D quartz column with front and back walls 15mm thick was designed and constructed. The column can resist an over pressure up to 1 bar; to avoid problems in case of a pressure build up inside the column, pressure release valves have been installed.

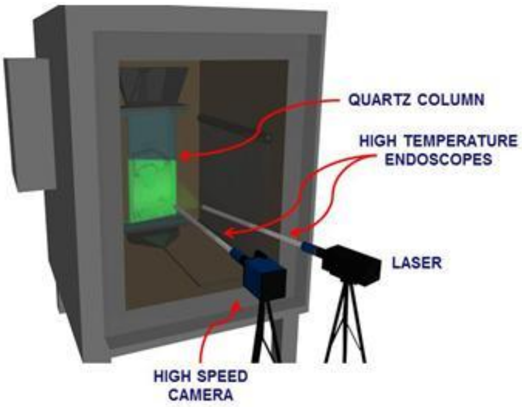

Figure 6. Schematic view of endoscopic-laser PIV/DIA

As for the gas feeding, a ceramic porous plate is attached to the bottom of the column. It can withstand the high temperatures and allows homogeneous distribution of gas inside the column. The average porous size of the porous plate is 40 microns. Special high temperature glue is used to paste the distributor to the quartz column and avoid gas leakage and channeling. All the piping, gas distributor, and freeboard are made of inconel® to withstand the high temperatures. The front door of the furnace is provided with holes for the insertion of both the optical high temperature endoscope and the customized laser endoscope.

The set up is automated and aligned with safety measures required for operation. Several thermocouples are attached to the quartz column to register the actual temperature. A pressure relief valve is installed in front the gas distributor, in case of over pressure the gas is vented. There is a nitrogen sweep line connected to the furnace for safety operation when using explosive materials, such as CH_4. A control system is implemented to automate the furnace operation and to operate the gas mass flow controllers. The control system also includes an emergency shutdown procedure.

CONLCUSIONS

A novel technique (ePIV/DIA) has been developed by coupling a high speed camera and a Nd:Yag laser with high temperature endoscopes, allowing PIV/DIA to study the hydrodynamics of gas-solid fluidized beds at high temperatures. A first validation of technique has been done at room temperature in a cold flow set up. It is shown that the use of the optical endoscope and the laser has marginal influence in the estimation of the solids profiles in comparison to the standard PIV/DIA measurements. A lab set up has been designed and constructed for the implementation of the endoscopic-laser PIV/DIA under production relevant - conditions.

REFERENCES

1. Bokkers, G.A., Van Sint Annaland, M. and Kuipers, J.A.M. Powder Technol., 140 (2004) 176-186.

2. Laverman, J.A., Roghair, I., Van Sint Annaland, M. and Kuipers, J.A.M. Can. J. Chem. Eng., 86 (2008) 523-535.
3. Rottier, C., Godard, G., Corbin, F., Boukhalfa, A.M., Honore, D. Meas. Sci. Technol. 21 (2010) 115404.
4. De Jong, J.F., Odu, S.O., van Buijtenen, M.S., Deen, N.G., van Sint Annaland, M., Kuipers, J.A.M. Powder Technol. 230 (2012) 193-202.
5. De Jong, J.F. Membranes in fluidized beds. PhD ThesisEindhoven University of Technology. ISBN: 978-90-386-3124-0.