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Optical Tomography: The potential of mass flow rate in rice industry

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ABSTRACT

The capability of Optical Tomography (OT) to visualize pipe flow is undeniably beneficial and of utmost importance to solid gas industry. The other striking feature of OT is its ability to measure and analyze real-time mass flow rate (MFR), which enables online monitoring of material weight. This paper addresses the problem posed by online weighing system in rice industry. The current system slows down the overall industrial production by impeding the device operation, and is therefore becoming obsolete. To overcome this drawback, we confirmed that OT has great potential in online weighing process using a polynomial equation. In addition, MFR measurement can gauge weight loss of rice during the enhancement process. Encouragingly, the application of novel MFR technique to accurately monitor weight loss of rice has proven to outperform the existing system in rice industry.

1. Introduction

The expression "tomography" is derived from the Greek word which means a slice of image. Technically, tomography is about obtaining two- or three-dimensional, cross-sectional images of an *N*-dimensional object [1]. Historically, tomography has been adopted in many areas of physical sciences and engineering to measure the distributions ("images") of parameters of interest in various processes [2]. Nowadays, tomography technique has expanded it applications to both industrial and medical fields. For OT in particular, the researchers from Universiti Teknologi Malaysia (UTM) are recognized as the most established group who applies this methodology for industrial purposes. They focus mainly on system development to visualize the solid gas images in the pipeline [3–5].

In solid gas industry, it is necessary to examine the pipeline, detect blockages, and verify whether the measured particles flow as required [6]. Apart from that, another important issue is to monitor the production loss, for instance, in rice industry. Notably, this unique grain sustains two-thirds of the world's population [7]. We hypothesized that the process of weighing rice before and after rice enhancement is essential for tracing losses in the rice industry. We confirmed our conjecture by visiting a leading rice manufacturer in Malaysia—Syarikat Faiza Sdn Bhd [8]. Fig. 1 reveals the position of Intake Weigher pre- and post-enhancement process—that is, before Polisher and after Color Sorter. This step plays a crucial role in checking the loss of rice during enhancement process. Nevertheless, the utilization of this device in weighing procedure slows down the overall process and has thus been abandoned by Syarikat Faiza Sdn Bhd. Besides, the existing system provides only the measurement readings but is unable to observe material distribution and movement in the pipeline [9]. To address these inadequacies, our OT-dependent MFR meter significantly shortens the rice weighing process in addition to enabling visualization of tomographic images inside the pipeline. With the aid of this system, problems such as blockages and unexpected processing results that may affect the flow of solids and reduce the effectiveness can be resolved easily.

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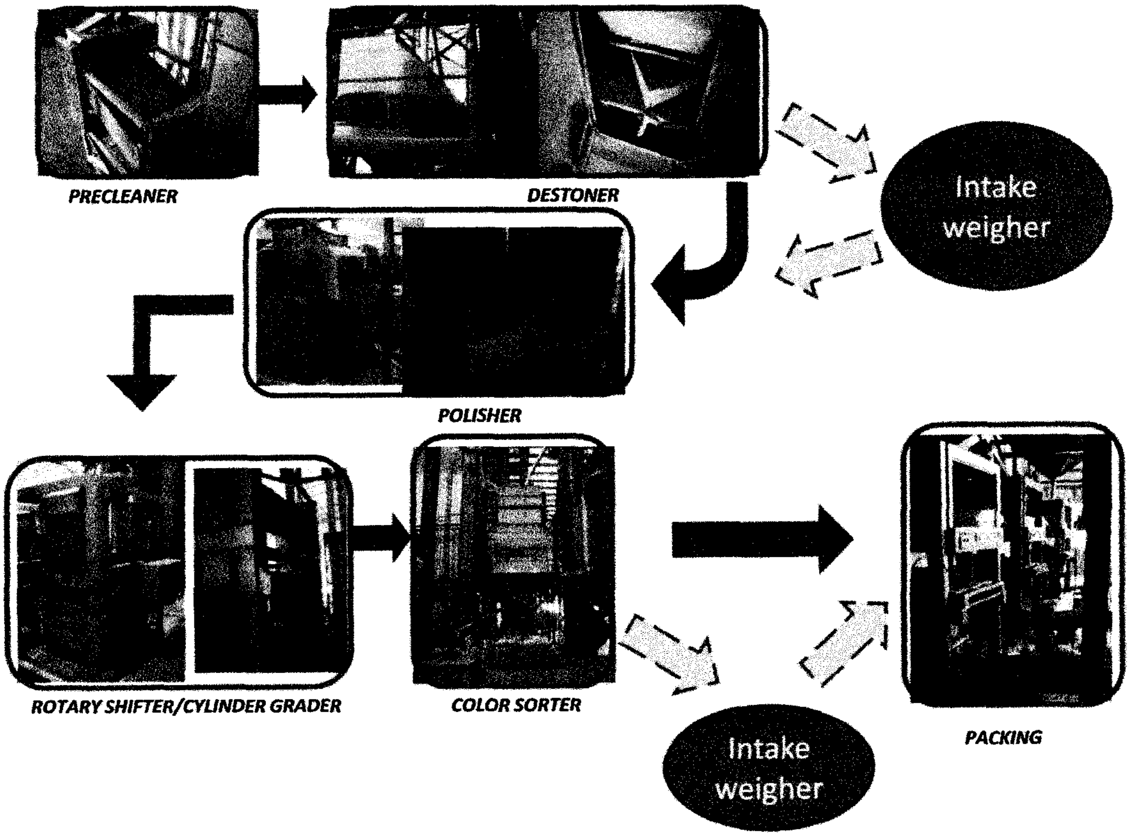


Fig. 1. The fresh rice processing to enhance its quality before goes to the market.

2. Overview of Optical Tomography and its operation

OT is one of the techniques that can replace Intake Weigher to accurately and instantaneously measure the weight as well as to visualize the material inside a pipe. By this, the output and quality of product are enhanced respectively. Fig. 2 shows the OT main operating system which consists of three vital sub-systems—sensor array, signal conditioning unit, and data acquisition unit. In brief, the master unit controls the slave by activating it to send a signal to the light projection circuit. Then, the receiver (see Fig. 3) responds to the signal, converts it into voltage, and the resulting voltage value will subsequently loop back into the slave. The slave in turn converts the analog voltage value into a digital datum that will be stored in its buffer until the user clicks on the GUI in the PC to activate the master and assemble all data based on I2C protocol. Once the data are received by the master, they will be

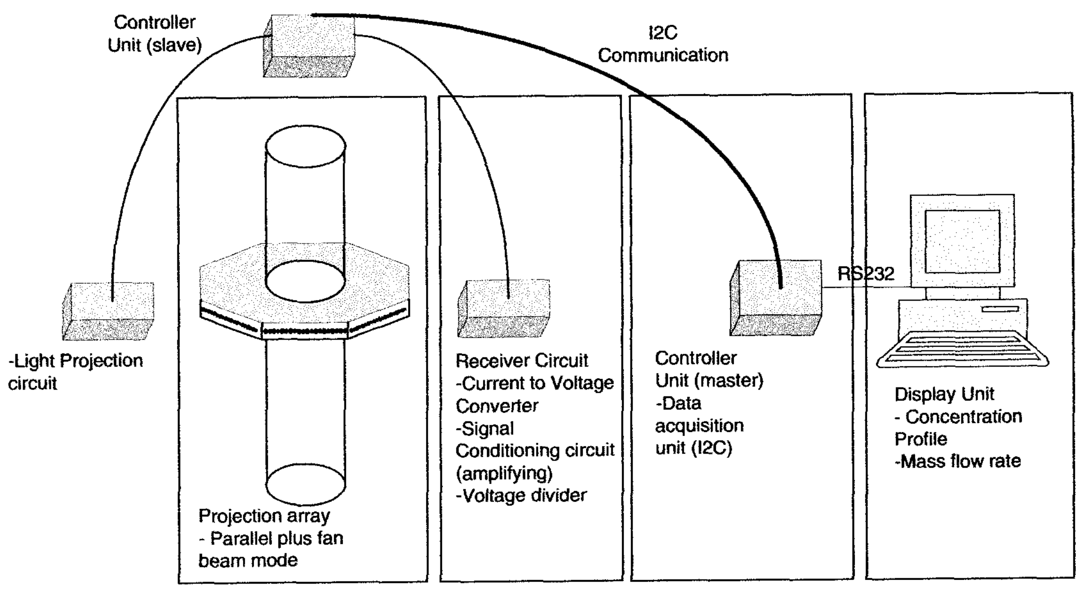


Fig. 2. The OT main operating system.

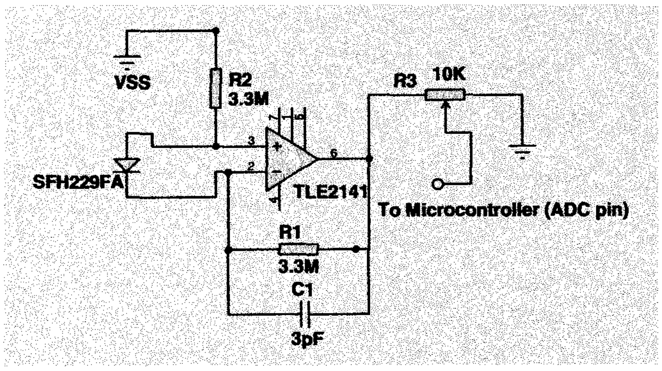


Fig. 3. Receiver circuit.

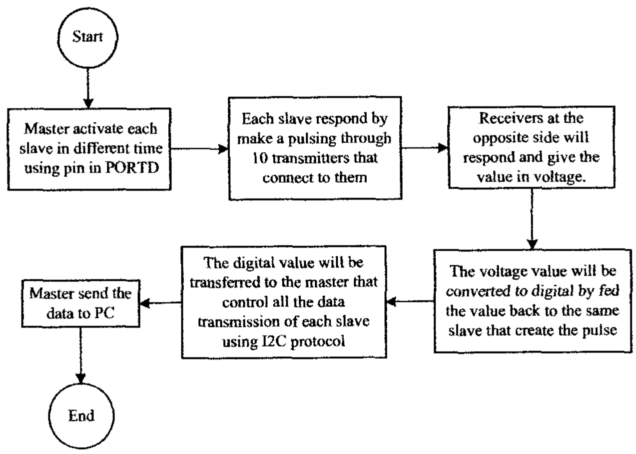


Fig. 4. Flow chart for interaction between master and slave operation.

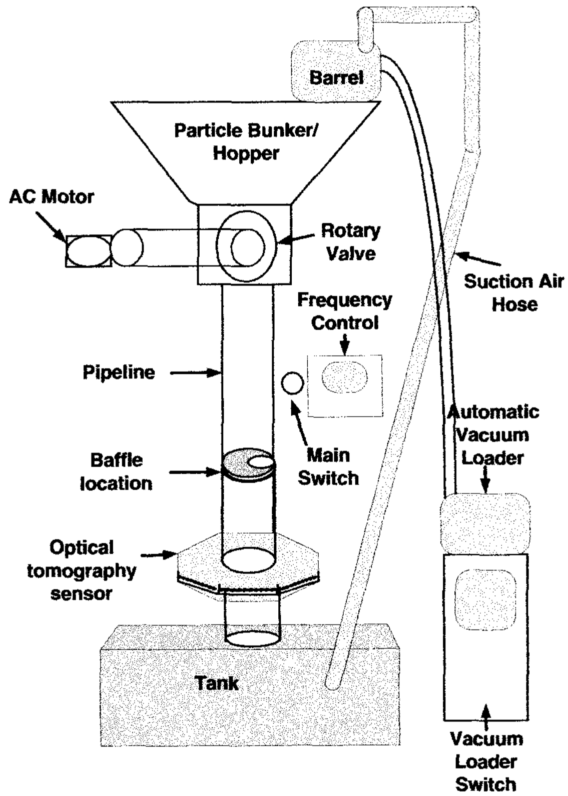


Fig. 5. The gravity flow rig.

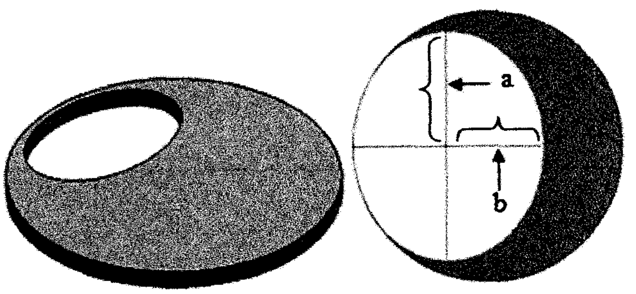


Fig. 6. Baffle sample as a concentration percentage indicator.

transmitted to PC according to RS232 protocol. These processes are illustrated in Fig. 4. Impressively, this system allows simultaneous MFR measurement and visualization of the material inside.

3. Mass flow rate measurement by optical tomography

MFR is an important parameter in industrial process that involves delivery of material. From the mass flow we may obtain information on the weight to be transported from one end to another. There are two types of measurement for calculating MFR—inferential or direct method [10]. Inferential method entails complex mathematical algorithm and computational model. Research studies by Carter and Yong is one example of inferential method. They integrated electrostatic sensor with digital imaging sensor to establish MFR at chosen velocity and volumetric concentration [11]. Our research derived MFR from the inferential method—where MFR of solids was from optical attenuation from the instrument [12]. In our research, we employed an optical sensor of which the calibration coefficient was multiplied by the concentration percentage [13]. Whereas the calibration coefficient is given by the slope of calibration line, the average concentration of solids in gas–solid flow is obtained using light attenuation/scattering methods [14]—the linear relationship between them had already been validated [15].

Next, the online MFR value is generated by implementing the MFR equation derived from the calibration graph of MFR versus concentration percentage. This equation will be inserted into the image reconstruction program. The calibrated MFR value is then obtained by manual weighing of plastic beads that flow through a gravity flow rig as shown in Fig. 5. Each time the plastic beads flow through the gravity flow rig, their weight is divided by the time taken in second, as indicated in Eq. (1).

$$\text{Mass flow rate} = \frac{\text{weight}}{\text{time}}\ [\text{kg/s}] \quad (1)$$

In our study, the measurement was differentiated by 10 different baffles with openings ranging from 0% to 100%. Each baffle corresponded to a specific concentration percentage. Fig. 6 displays the baffle used for this study. As presented in Fig. 7, the baffle was placed above the OT system. Each measurement was repeated five times to produce an average value, and the resultant concentration percentages coincided with the different baffle openings. On the other hand, the selected plastic beads had an average diameter of 2.70 mm and an average height of 3.32 mm. Ultimately, this experiment was intended to verify the equation from the calibration experiment that could potentially be used in the online MFR measurement. The results from the calibration graph are revealed in Fig. 7. In the case where the measurement involves a different type of material, recalibration will be required.

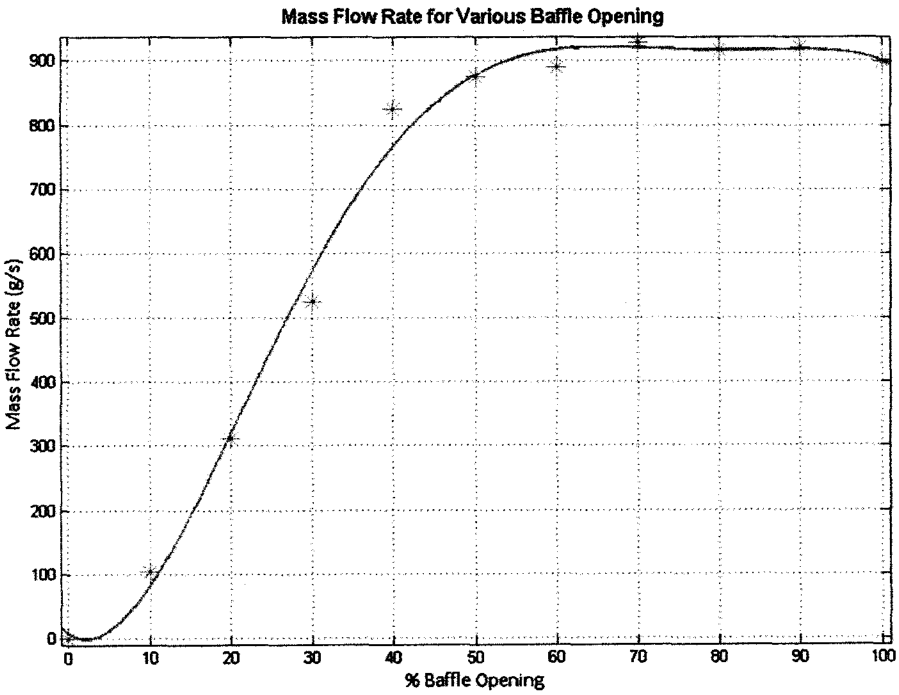


Fig. 7. The mass flow rate value using different baffle.

In Fig. 7, the curve increases proportionally up to 70%. After which a saturated trend is observed, that is, the values are approximately the same from 70% to 100% baffle openings. The equation for calibration graph is a fifth degree polynomial as follows,

$$y = p1x^5 + p2x^4 + p3x^3 + p4x^2 + p5x + p6 \quad (2)$$

where y = mass flow rate; x = flow regime; $p1 = -1.514e^{-6}$; $p2 = 0.0004522$; $p3 = -0.0481$; $p4 = 1.969$; $p5 = -7.872$; $p6 = 6.69$.

4. Result and analysis

When applying direct method for measuring MFR, Eq. (1) will be applied. Here, the baffle opening corresponds to the concentration percentage in the tomogram, and it equals to x value in the graph while y denotes MFR. Before measurement begins, the gravity flow rig must first be calibrated. Each measurement is repeated ten times. The voltage is linearly related to concentration as it depends on the size of obstruction. In other words, the concentration has a linear relationship with MFR.

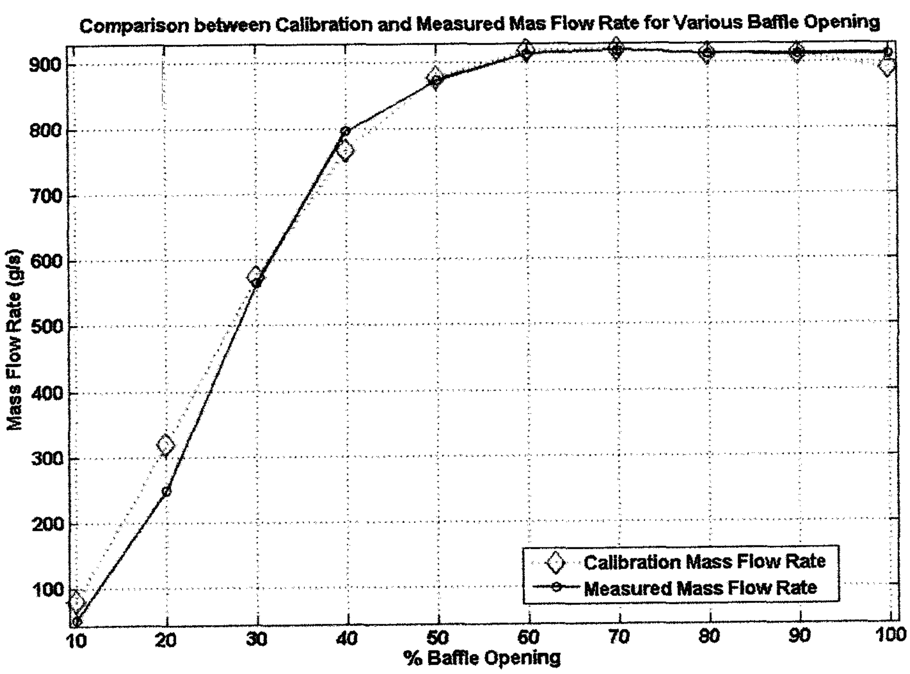


Fig. 8. Comparison between calibration and measured mass flow rate for various baffle opening.

Table 1
Concentration profile for different baffle opening.

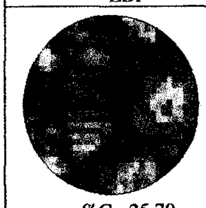
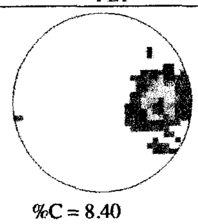
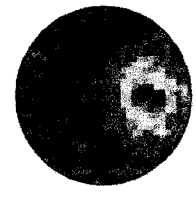
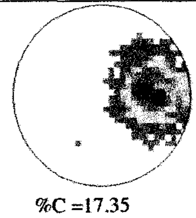
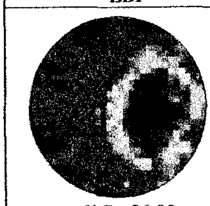
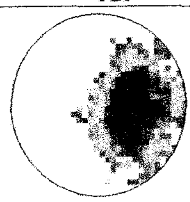
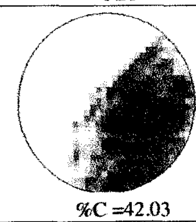
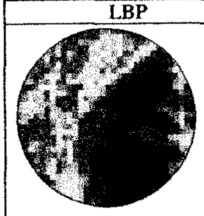
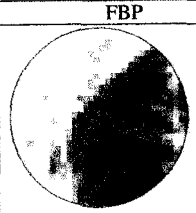
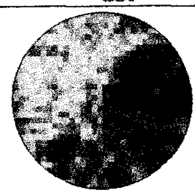
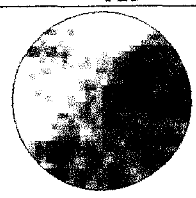
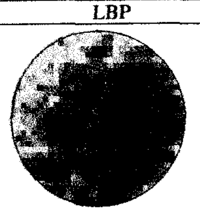
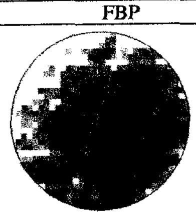
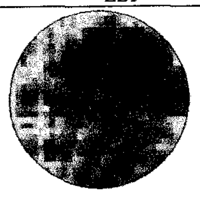
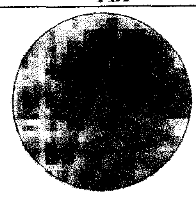
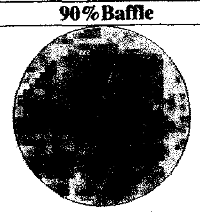
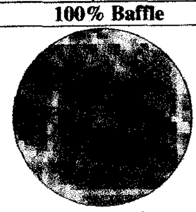
10% Baffle		20% Baffle	
LBP	FBP	LBP	FBP
			
%C =25.70	%C = 8.40	%C = 39.46	%C =17.35
30% Baffle		**40% Baffle**	
LBP	FBP	LBP	FBP
			
%C =56.90	%C =29.61	%C=70.73	%C =42.03
50% Baffle		**60% Baffle**	
LBP	FBP	LBP	FBP
			
%C =76.92	%C =49.46	%C =79.49	%C =57.81
70% Baffle		**80% Baffle**	
LBP	FBP	LBP	FBP
			
%C=84.16	%C =70.48	%C =84.04	%C = 81.38
90% Baffle		**100% Baffle**	
			
%C =83.42		%C =85.00	

Table 1 displays the concentration profile from the gravity flow rig experiment using baffle openings ranging from 10% to 90%. The acquired real-time image was reconstructed based on Linear Back Projection (LBP) algorithm—a well-known algorithm that produces an image via multiplying voltage loss by sensitivity map [16]. The entire image was filtered with Filtered back Projection (FBP) algorithm, which adopts the threshold concept in filtering an image produced by LBP [17]. To be accurate, the concentration profile was obtained by FBP technique along with Eq. (1), and was subsequently used to compute MFR. Our proposed approach differs from the widely accepted technique [14] that took into account only the linear segment of the graph—from 0% to 50%—when deriving the linear equation. The major drawback of such linear equation is that it yields inexact MFR values for concentrations beyond 50%, which region is in fact nonlinear. Conversely, our technique relies on a polynomial equation for concentration percentages from 0% to 100%, and is presumably more accurate. As demonstrated in Fig. 8, the measured values for concentration percentages from 70% to 100% match well with the calibration curve.

Following FBP, the generated tomogram was employed for calculating the measured MFR since its concentration profile was devoid of noise. Table 2 lists the calibrated and measured MFR values as well as the error differences of MFR. To ensure accurate and reliable results, the values of calibrated and measured MFR were taken ten times to obtain the average values. Visibly, the highest error difference was found in 10% flow regime whereas the lowest was identified in 70%. It is noteworthy that both 10% and 20% flow regimes exhibited high error differences between calibrated

Table 2
The difference between measured and calibration mass flow rate.

Flow regime (%)	Computed C (%)	Calibration mass flow rate	Measured mass flow rate	Error difference (%)
10	8.40	81.14	53.23	−34.40
20	17.35	319.56	250.23	−21.69
30	29.61	573.42	564.27	−1.60
40	42.03	766.40	795.45	3.79
50	49.46	876.22	872.32	−0.45
60	57.81	916.40	912.09	−0.47
70	70.48	918.19	917.89	−0.03
80	81.38	912.37	912.01	−0.04
90	83.42	911.03	911.70	0.07
100	85.00	889.49	911.61	2.49

and measured MFR. This is because small baffle hole will exert very high pressure on the passing material. Therefore, the high pressure concentrated at the center of the baffle hole will create a dropping particle in that specific area. As a result, the concentration profile will be smaller than the baffle hole, and it consequently affects the result of measured MFR. It is noticeable for 100% flow regime that is slightly drop on the calibrated result compared to the measured result. This discrepancy may due to the intolerance during the calibrated process but apparently it still contributed to the maximum MFR up to a limited amount. Finally, for flow regimes from 30% to 90%, the error differences were relatively low since the baffle openings interacted smoothly—the pressure was neither too high nor too low—with the dropping particles, thereby yielding comparable MFR results. Fig. 8 depicts the differences between calibrated and measured MFR.

5. Conclusion

In solid gas industry, the need for MFR measurement is indispensable. Building on this concept, our proposed OT system holds great promise for substituting the existing system in the rice industry. Its implementation can facilitate online loss monitoring during the enhancement process and, additionally, the tomogram inside the pipeline may also be visualized.

Acknowledgement

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Biographies

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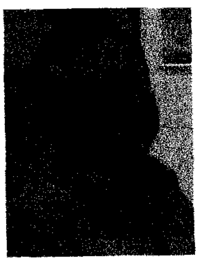

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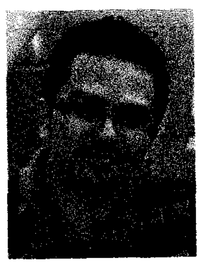

Mohd Hafiz Fazalul Rahiman received B.Eng. (Hons) degree in electrical (control and instrumentation), M.Eng. and PhD degree in electrical engineering from Universiti Teknologi Malaysia (UTM), Johor, Malaysia, in 2003, 2005, and 2013 respectively. In 2006, he joined Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia, as a teaching staff member and at present he holds senior lecturer position. His research interests include process tomography, sensors and instrumentations.

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