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Symposium of Emerging Nuclear Technology and Engineering Novelty (SENTEN 2018)

PREFACE

Following the previous successful of SENTEN-ICoNETS 2015-2017, five research centers under the Deputy of Nuclear Energy Technology – National Nuclear Energy Agency of Indonesia (BATAN) in collaboration with Universitas Sriwijaya organize the First Symposium of Emerging Nuclear Technology and Engineering Novelty (SENTEN) with theme:"Discovering Science and Engineering Novelty for improving human life prosperity". SENTEN 2018 has been conducted in Horison Ultima Hotel, Palembang, South Sumatra, Indonesia, on 4-5 July 2018. This conference aims at summarizing recent research activities relevant to the nuclear, material, mechanical, electric, chemical, geology, architect and civil engineering, computer science and IT, food and agriculture, and also facilitate communication among relevant experts.

More than 150 people from Indonesia, Malaysia, India, Taiwan, and some other countries have participated in this conference. About 207 presentations including 6 keynote speeches and 1 plenary talk are presented. The presentations are grouped into 9 areas of particular interest: (1) Nuclear Science and Engineering, (2) Material Science and Engineering, (3) Mechanical and Industrial Engineering, (4) Electrical Science and Engineering, (5) Chemical Science and Engineering, (6) Geological Science and Mining Engineering, (7) Architecture and Civil Engineering, (8) Computer Science and Information Technology, and (9) Food and Agricultural Science, Natural Resource Science.

From about 190 full papers submitted, then peer-reviewed by relevant experts, eventually 169 papers were accepted for publication in this proceeding. We are indebted to all of authors for submitting their original papers.

We would like to thank all participants, and express our gratitude to all those who helped the success of this conference.

Syaiful Bakhri

SENTEN 2018 Chairman

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All papers published in this volume of Journal of Physics: Conference Series have been peer reviewed through processes administered by the proceedings Editors. Reviews were conducted by expert referees to the professional and scientific standards expected of a proceedings journal published by IOP Publishing

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Challenges in Turbine Flow Metering System: An Overview

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Abstract. This paper presents an overview of turbine flow meter (TFM). State of the art, the basic concept of TFM, and some parameters that influence the robustness of TFM are described. In addition, some challenges that occurred in TFM that can affect the accuracies of the measurement are also analysed. The different meter reading between the manual metering or turbine stand meter and Electronic Volume Corrector (EVC) that occurs in turbine flow meter in oil and gas industries is one of TFM challenges. This difference leads to losses in customers or in industries themselves. A notification system is proposed in this paper. An intelligent system that can determine the occurrence of the error will be embedded to the system. It is hoped that by having the earlier notification, the losses can be decreased.

Keyword: Artificial Intelligence, Electronic Volume Corrector, Meter Bouncing, Notification, Turbine Flow Meter

1. Introduction

Measuring fluid flow rate (gas or liquid) in real-time becomes one of the most important things in many applications, such as in industry, oil and gas trade, health [1], and other applications [2]. The characteristic of the fluid that is able to change easily in different ways made it become not always remain stable. To overcome this problem, a flow meter with high precision and fast response is of significant need. There were a lot of flow meter types that have been invented by previous researchers; some of them are coriolis [3], venturi [4], orifice [5], ultrasonic [6], and turbine [7] flow meter.

Turbine flow meter has been investigated for a decade due to the economy of installation, low maintenance costs [8], compact (with small size), high stability, precision [7], direct volume readout and wide measurement range [9]. It has succeeded to measure not only the liquid but also the gas. It can be used to measure the billing meter for water and gas flow in private house, office, hotels, apartment complexes, and other commercial buildings. It can also be applied to measure the oil in upstream and downstream of refineries or process liquid in industrial and pharmaceutical chemicals [10]. In conducting the measuring tasks, the turbine flow meter should offer a good performance. It should provide a correct measurement. However, the flow condition in the pipelines usually shows its consistency. The fluid supply and demand fluctuated every time [11]. It could decrease the performance of the turbine flow meter. Therefore, a robust turbine flow meter is really needed.

The accuracy of the flow meter can be obtained using accurate calibration. Turbine flow meter must be properly and periodically calibrated [12]. Unfortunately, even with a well installed and calibrated, turbine flow meters sometimes showed bad performances [13]. Error deviation that is disadvantageous always occurs as its effects. This paper has an objective to analyze the challenges that cause incorrect measurements of turbine flow meter.

2. Turbine Flow Meter Technology

Previous researchers introduced some flow meters that can handle the measurement of the fluid. In general, the flow meters can be categorized into 2 groups, i.e. inferential and positive displacements [5]. In other researches, they were divided into many classifications, such as: (i) proposed by Furio [9] that divided the flow meter into 3 groups, i.e. inferential, differential pressure and positive displacements; (ii) introduced by Richard [14] that classified the meters into 3 groups, i.e. pressure differential meter, insertion volume, and mass; (iii) presented by Frenzel [15] that grouped the flow meters into 2 main classes (Figure 1). In Frenzel's classification, the division of the groups is based on 2 criteria, namely 1) in closed pipe lines and 2) open channel and free surface pipe lines.

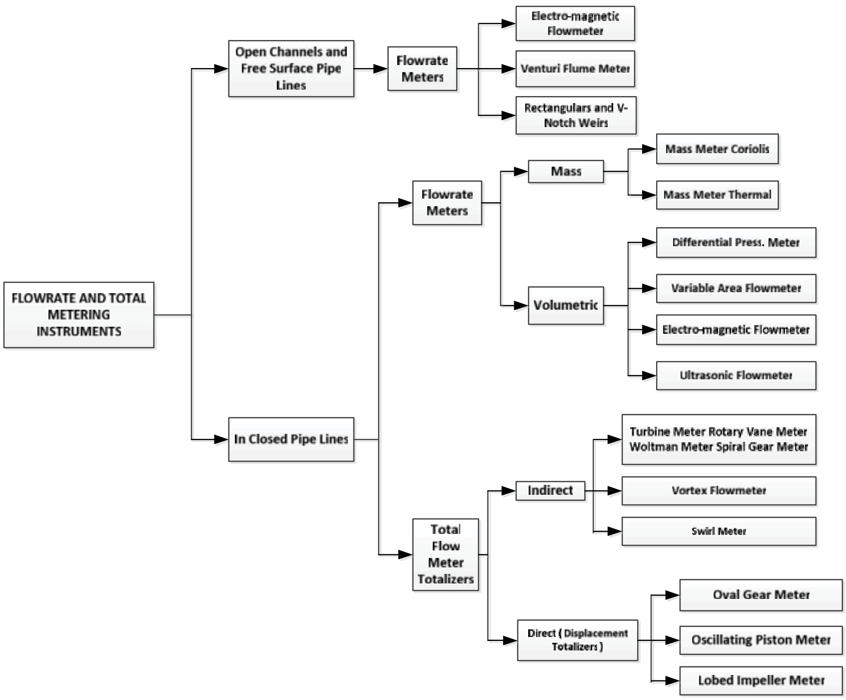

Figure 1. Classification of Flow Meter

The inferential flow meter usually does not measure the volume, velocity or mass directly, but measures flow by inferring its value from other measured parameters, in other word this metering measures the rate of the flow [5]. That is why some references categorize the inferential flow meter as indirect flow meter that measures gas flow volumes by counting the revolutions of the rotor [16]. Flow meters that included as inferential flow meters are: orifice, ventury, flow nozzle, pitot, dall tube.

Differential pressure meters are devices that derive the volumetric flow rate through the measurement of a difference of static pressure between two suitable pressure taps. They work based on the pressure differences that depends on the Bernoulli's theorem and the continuity equation. Some examples of differential pressure meters are orifice plates, nozzles, rotameter, etc.

Positive Displacement meters are actually counter meters. It separates the incoming gas into a series of known discrete volumes and then totalizes the number of volumes. This meter directly measures the volume of the fluid that passed through a pipe. Some examples of positive displacement meters are rotary piston, gear, helical, weir, sluice gate, open channel flow meter, and diaphragm flow meter.

2.1. State of The Art Turbine Flow Meter

The history of turbine flow meter started when the first turbine flow meter was invented by Reinhard Woltman in 1790 [10] [12]. Most of the researchers in that time focused on analyzing the turbine flow meter in steady flow [17]. In 1960, the topic of the researches was shifted to the design the blade shape of the turbine flow meter. Some of the researchers also established some mathematical model of the rotation of the impeller in order to analyze the torque on different part of blade. By having numerical method, the development cycle of new products could be shortened and the cost of the development could be reduced [1]. However, the model still could not describe the internal flow field and the velocity distribution [12]. Moreover, during rotation process of the blade, its precision calculation was also affected by many phenomena, such as separation, whirlpool and reflux [12]. Recently, most of the researches were interested in two research scopes, including the numerical simulation technology and turbine flow meter calibration and measurement (see Table 1). Most usable simulation software in flow meter was computational Fluid Dynamic (CFD). It is a tool for simulating many applications with high accuracy and flexibility.

Table 1. Recent Turbine Flow Meter Researches

Year	Author	Technique/method	Results/Advantages	Type	Ref
2013	Suna Guo	CFD simulation	viscosity and linearity error increased; average meter factor of turbine flow meter decrease	Experiment/Simulation	[2]
2014	Z. Saboohi	Finite difference calculation and CFD simulation	Accurate Result	Simulation	[18]
2015	Y. Z. Huang	Cavitation modeling	Could predict the cavitation	Simulation	[8]
	Paul W. Tang	Describe some factors that affected the error occurred in the measurement	Offered an accuracy measurement by using optimization	Experiment /Simulation	[16]
	Xin Jin	Mathematical modeling using AMESim	Could manage the high frequency oscillation	Simulation	[19]
	Pedišius Nerijus	Comparing the measurement and rotary vane and turbine flow meter	Forecast measurement accuracy	Experiment/Simulation	[20]
	LI Dong-hui	Drift-flux model	Could manage the error	Simulation	[21]
	Furio Cascetta	Addition new original formulae	on-off cycles influenced the extra rotation	Experiment/Simulation	[9]
	Carl L. Tegtmeier	CFD modelling	Steady state rotor speed	Simulation	[12]
2016	Mohammed Liaket Ali	Design and build TFM using Arduino	precise result with 3% error	Experiment	[22]
	Guo Suna	CFD	Showed the optimal flow meter performance	Simulation	[23]
2017	Y. Yuang	workbench	adaptive measurement	Modelling/ Simulation	[7]
2018	Z. Džemić	High Frequency Signal	Suggest a good dynamic response	Experiment/Simulation	[24]

Many researchers tried to make new design and optimization of turbine flow meter. Tegtmeier in [12] analyzed the calibration of gas turbine using CFD. A model was established to imitate the real experiment of turbine flow meter. A variation of the flow rate, viscosity, and density was set up in order to reach a stable rotor speed. The model gave some results that can be used to improve the turbine flow meter in the future [12]. Some other researchers that used CFD in their researches can be seen in Table 1.

For the real design, it can be seen in research proposed by Ali in [22]. The research showed a design of turbine flow meter that could record the flow rate and the temperature of fluid. The design

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managed to measure the flow of the fluid by utilizing the opto-sensor that grabbed the rotation of turbine and transmitted the pulse signal to the microprocessor. The error produced by the design was really small (3%).

2.2. Turbine Flow Meter Basic Concept and Equation

The turbine meters can be used to measure various flow rates, operating pressures up to 10,000 pounds per square inch, temperature range of -450° to 1000°F [8]. Turbine flow meter in basic concept utilizes the spin of the rotor. The rotor spins when fluid passes through them. The force of the fluid current makes the rotor to spin. Therefore, the rotor in general rotates proportionally to the flow rate. For detecting the rotational speed of the rotor, a pick off sensor is needed. Typically, the pick off sensor is equipped with a magnet and rotating conductor. This magnet has a chance to count the rotation of the rotor of the turbine [10]. When plate blades cut through the flow helically, the value of velocity v and frequency f, can be generated using equation (1) and (2) [25]. In its application, turbine flow meter consisted of many types, as shown in Table 2 [10].

$$v_a = \frac{v}{\tan\beta} \tag{1}$$

$$f = \frac{N \tan\beta \, v_a}{2\pi r} \tag{2}$$

where v_a is the axial velocity, v is the blade velocity, β is the blade angle, N is the number of the blade, and r is the radius of the blades.

Table 2. Flow meter Turbine Types [10].

No.	Type	Principles	Application
1	Axial	The rotor of this type revolves around the axis of flow	industrial liquid, oil or gases measurement
2	Single Jet/ Multi Jet	It has orifices that lead the fluid into blades so that it turns.	municipal, commercial, and industrial water measurement
3.	Paddlewheel	The paddlewheel is light and the blades are flat. The blade spins to flow rate proportionally	to measure low-speed flows
4.	Pelton wheel	It is almost the same with paddlewheel, but it has a single size rotor and the blade is straight	to measure low flow rates of low-viscosity
5.	Propeller	The blade is helical-shaped. This type has longer and fewer blades than the other type	to measure dirty fluid
6.	Woltman	The axis of the turbine is in line with the flow direction	to measure larger volume

2.3. Parameters in Turbine Flow Meter

2.3.1. Viscosity

Viscosity is one of important factors in turbine flow meter performance. When the viscosity is low (1 cSt (centistokes) or below, as in water), the response of the flow meter depends on the flow rate linearly [12]. However, when the viscosity is high (20 to 100 cSt, as in hydraulic fluid), the response of the flow meter is really non-linear [12]. Tegtmeier [12] analysed the effect of viscosity to the turbine flow meter measurement. The result of the research could be very useful for calibrating and designing turbine flow meters.

The viscosity exists not only in liquid but also in gases. The values are appreciably smaller than for liquids and increase with temperature [15]. It is contradictive with liquids where its viscosity reduces with increasing temperature [15]. The viscosity has a tight relation with pressure and temperature. The increasing of viscosity affected the decreasing of the pressure. Therefore, an additional energy is needed to increase the pressure, so that the fluid can manage its rate of flow [26]. Meanwhile, the increasing of the temperature will decrease the absolute viscosity. Thus, the turbine flow meter performance will also be affected by the temperature [26].

Turbine flow meters that are usually used to measure high flow rate are needed to be calibrated for atmospheric pressure. The kinematic viscosity will decrease as the effects of the gas density growth due to the increasing of pressure. This condition leads to the difficulty of extrapolating the laboratory calibration result to operating conditions [20]. The ratio for absolute viscosity to density in equation (3) is called Kinematic Viscosity (v) [26].

$$v = \frac{\mu}{\rho} \tag{3}$$

where, v is kinematic viscosity; μ is absolute viscosity; and ρ is density

2.3.2. Reynold Number

According to Paul [16], Reynolds number (Re) is a dimensionless ratio that related to the gas flow rate, the meter run diameter, and the properties of the gas. For low Re (below 2000) where the viscous forces are dominant, the flow laminar will take place. In contrast, when the Re is high (above 4000), the turbulent flow will occur due to the domination of inertial forces. For Re between 2000 and 4000, a transitional state will dominate. In this condition, the system shows its instability.

The Re can be calculated using the equation (4):

$$Re = \frac{\rho v D}{\mu} \tag{4}$$

where, ρ is density; v is velocity; D is diameter; and μ is dynamic viscosity.

To reach the dynamic similarity of fluid flow, many researchers took into account a Reynolds number [24], [16]. When the same Re was exposed to an object, the characteristics of that object would be the same. For instance: with the same Re, the rotation of the rotor in a turbine meter would have same angular velocity [24].

2.3.3. Cavitation

Cavitation in a turbine flow meter refers to an empty space that occur due to the decreasing of local pressures near or below the vapor pressure [8]. It can cause the rotor to speed up at the high flow rate due to the increased flow volume and causes the accuracy curve of the turbine flow meter to be adversely affected [8]. Navier-Stokes equations in equation (5) –(8) are the most common formulas used in describing the cavitation models. Equations (5), (6), (7), and (8) are mass conservation, momentum equation, transport equation for cavitation dynamics of vapor volume fraction, and mass transfer.

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_j) = 0 \tag{5}$$

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_j u_i) = \rho g_i - \frac{\partial \rho}{\partial x_i} + \frac{\partial \tau_{ji}}{\partial x_i} \tag{6}$$

$$\frac{\partial \alpha_v \rho_g}{\partial t} + \frac{\partial}{\partial x_j}(\alpha_v \rho_g u_j) = S \tag{7}$$

$$S = \dot{m}^+ + \dot{m}^- \tag{8}$$

Where:

$$\dot{m} = \dot{m}^+ + \dot{m}^- = (\frac{2\xi}{2-\xi})\left(\frac{M}{2\pi R}\right)^{\frac{1}{2}}\left(\frac{P_v}{\sqrt{T}} - \frac{P}{\sqrt{T}}\right)A \tag{9}$$

2.3.4. Calibration

Calibration means improving the reading of meters by comparing the measurement of the device with the standard one [27]. Some settings that are trained to the device are really needed to enhance the calibration result. Calibration techniques that are frequently used are presented in Table 3.

Table 3. Calibration Techniques

No.	Calibration Techniques	Drawbacks	Ref
1.	Hydrocarbon flow meter calibrations, the standard Stoddard solvent	volatile and poses an environmental and health risk to those performing the calibrations.	[12]
2.	A mixture of propylene glycol and water	the density of the propylene glycol and water mixture is 15% higher than that of the volatile fluid.	[12]
3.	Physical models for the turbine meter calibration curve based on momentum and airfoil approaches	should be supplemented with experimental correction factors to improve accuracy.	[12]
4	UVC (Universal Viscosity Calibration)	− only for the linear range. − it does not compensate for other temperature and pressure effects such as flowmeter body expansion	[26]
5	Adaptive Calibration of Turbine Flow Measurement using ANN	A simulation experimental only, not the real one	[28]

3. Challenges in Turbine Flow Meter

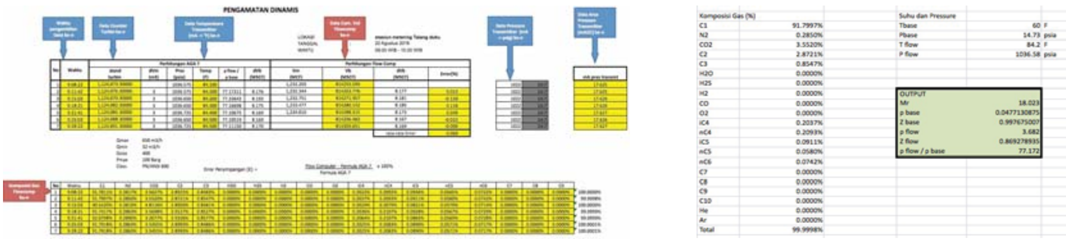
Common troubles that always occur in turbine flow meter are usually caused by the cavitation, viscosity, debris on rotor stator, mechanical vibration, and faulty pick up [29]. Cavitation can make the turbine flow meter misread the actual flow rate; the value becomes higher or lower than the real one. The lower reading of the flow meter indicates that there is higher viscosity that occurs in the flow, while the lower one shows that there may be gas which presents in the flow. To overcome those problems, the meter should be cleaned or recalibrated [29]. General detail troubles, causes, and how to resolve the problems in turbine flow meter are presented in Table 4.

Table 4. Troubles, cause and remedy [29]

Trouble	Possible Cause	Remedy
Meter indicates higher than actual flow rate	− Cavitation − Debris on rotor support − Build-up of foreign material on meter bore − Gas in liquid	− Increase back pressure − Clean meter − Clean meter − Install gas eliminator ahead of meter
Meter indicates lower than actual flow rate	− Debris on rotor − Worn bearing − Viscosity higher than calibrated	− Clean meter and add filter − Clean meter and add filter − Recalibrate monitor
Erratic system indication, meter alone works well (remote monitor application only)	Ground loop in shielding	Ground shield one place only. Look for internal electronic instrument ground. Reroute cables away from electrical noise
Indicator shows flow when shut off	Mechanical vibration causes rotor to oscillate without turning	Isolate meter
No flow indication. Full or partial open position	Fluid shock, full flow into dry meter or impact caused bearing separation or broken rotor shaft	Rebuild meter with repair kit and recalibrate monitor. Move to location where meter is full on start-up or add downstream flow control valve
Erratic indication at low flow, good indication at high flow	Rotor has foreign material wrapped around it	Clean meter and add filter
No flow indication	Faulty pick-up	Replace pick-up
System works perfect, except indicates lower flow over entire range	By-pass flow, leak	Repair or replace by-pass valves, or faulty solenoid valves
Meter indicating high flow, upstream piping at meter smaller than meter bore	Fluid jet impingement on rotor	Change piping
Opposite effects of above	Viscosity lower than calibrated	Change temperature, change fluid or recalibrate meter

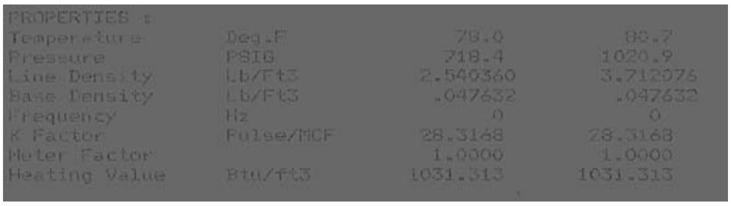
Troubles that occur in the turbine flow meter will affect its accuracies. The accuracies that are affected by real world implementation become one of challenges in turbine flow meter. According to Mark [13], some errors in measurement occur due to 3 factors, namely: 1. environmental temperature, 2. low static pressures, and 3. calibration before every tests. Some suppliers of the flow meter provide a standard spreadsheet to calculate the flow meter error using Microsoft Excel as shown in Figure 2.

The calculation using AGA 7 standard (in Figure 2) can be established by reading the screenshot data in stand meter (Figure 3). The gas parameters, such as volume, pressure, and temperature were then counted using the equation: $\frac{dV_m}{0.3048^3\,\rho_{flow}} : 1000$, to get the dV_b value of AGA7. The value of the dV_b of AGA 7 was then compared to the dV_b of Flowcom measurement. The Flowcom used the gas volume data of stand meter from the Gas chromatograph (GC), where the value of volume, pressure and temperature were based on the high frequency (HF) and low frequency (LF) that were read in real time in online system.



(a) (b)

Figure 2. Spreadsheet for calculating the flow meter error



PROPERTIES :			
Temperature	Deg.F	78.0	80.7
Pressure	PSIG	718.4	1020.9
Line Density	Lb/Ft3	2.540360	3.712076
Base Density	Lb/Ft3	.047632	.047632
Frequency	Hz	0	0
K Factor	Pulse/MCF	28.3168	28.3168
Meter Factor		1.0000	1.0000
Heating Value	Btu/Ft3	1031.313	1031.313

Figure 3. Screenshot data from flow computer

In this research, the gas volume measurement was done using two mechanisms, i.e. 1. using mechanic counter, 2. using electronic. In mechanic counter, the measurement was based on the mechanical gear. When the flow of the fluid passed through the gear, the rotation of the gear was then connected to a pulse counter (stand meter). This meter was read every week. In electronic, there are two ways of reading the pulse counter, namely high frequency (HF) and low frequency (LF). In LF, a reed switch with a magnetic principal mechanism was used as the pulse counter. Its principal works was similar to the contactors that generates the ON and OFF. In HF, a special sensor was used. The value of < 6.65, indicates that $k = 0.1\,m^3$, the value of $6.65 - 6.100$, indicates that $k = 1\,m^3$, and the value of > 6100, indicates that $k = 10\,m^3$. The measurement of LF and HF were done using EVC using online system by EVC and sent to the control center using Automatic Meter Reading (AMR). The dynamic test using LF is used due to it has less error than HF (figure 4). However, using LF can cause different reading between stand meter and flow com. The quality of the magnet determines the difference occurred in them. In some applications, some industries prefer HF to LF.

In oil and gas industries, the different meter reading between the manual metering or turbine stand meter and Electronic Volume Corrector (EVC) that occurs in turbine flow meter is called as meter bouncing. In general, they usually show different calculation. Manual metering usually used to display the output of the turbine flow meter. It measures the volume of gas flowing through them without considering its variation. In its application, to compensate the variation of volume that occurs due to the pressure and temperature changing of gas flow, the natural gas industries use EVC. By having EVC, true volume of natural gas that flows through the turbine flow meter can be calculated correctly. In general, the EVC calculates the electronic signal output obtained from the turbine flow meter and makes the correction of the volume based on AGA7 and AGA8 [30]. One of the examples of meter bouncing can be seen in Table 5 while the meter reading of system can be seen in Figure 5.

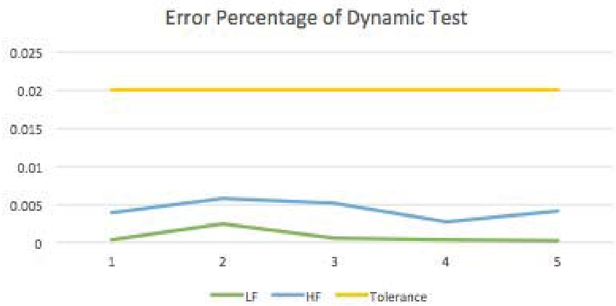


Figure 4. LF and HF error measurement percentage

Table 5. Meter Bouncing example (reprinted with permission of PT. PGN)

No.	Time	Turbine Stand Meter (m^3)	Pressure (BarA)	Temperature (^0C)	Meter Reading	
					Manual (AGA 7)	EVC (m^3)
1.	12.14	465246	4.41325	30.03	8.71	8.56
2.	12.19	465247	4.21325	30.01	4.16	4.30
3.	12.24	465249	4.21325	30.01	8.31	8.62
4.	12.29	465250	4.31325	30.01	4.26	4.28
5.	12.34	465252	4.31325	29.99	8.51	8.42
6.	12.39	465253	4.31325	29.99	4.24	4.17
Average/Total			4.3133	30.02	38.02	38.35

From Table 5, the reading meter difference can be calculated using equation (6)

$$Difference = \frac{EVC - Manual}{Manual} x\ 100\%$$

The difference was found 0,4 %.

The correction of meter misreading was then done as shown in Figure 5. It shows the meter reading of manual and EVC. Figure 5 (a) shows the condition of turbine stand mater. In that correction, the stand mater turbine showed the value 465253.0 m^3, with pressure 3.3 BarG and temperature 30 ^0C (Figure 5. (b) and 5 (c)), while the EVC showed the base volume 38.35 m^3, with primary volume 465253.0 m^3, pressure 4.2419 BarA, and temperature 29.98 ^0C. Number of bouncing accidents in 2016 and 2017 can be seen in Figure 6 (a) and (b).

(a) (b) (c)

Figure 5. The display of meter reading (a) turbine stand meter; (b) pressure; (c) Temperature
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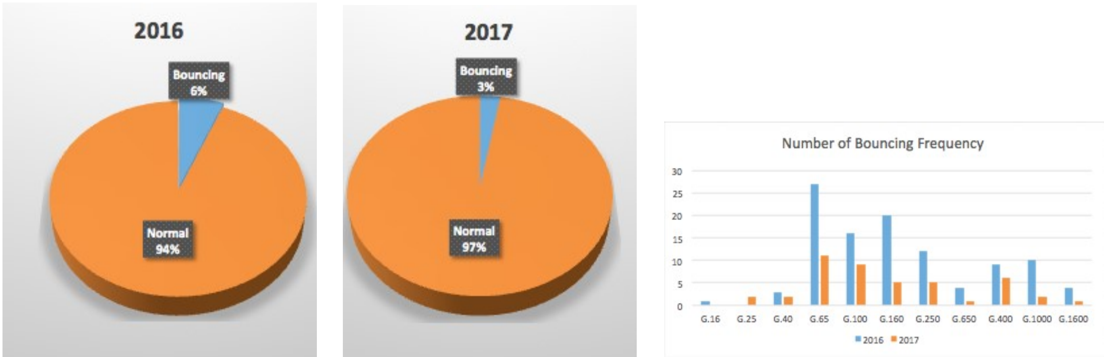

(a) (b) (c)

Figure 6. Bouncing percentage (a) 2016, (b) 2017, (c) Bouncing frequency

4. Proposed Research

To overcome the problem of meter bouncing, the author proposed a system that can minimize the error by making a system that has an ability to notify its occurrence. An Intelligent system will be added to the system. The signal from the flow meter, the pressure, and the temperature of the systems will be inputted to the fuzzy logic controller. Fuzzy will determine and decide whether the error reading between the stand meter and the EVC has occurred and send the output to the server. Fuzzy logic controllers has been widely used in various applications, such as for reaching a target [31], [32], navigating [33], [34], controlling robots [35], localizing odor [36], maintaining formation [37]. However, only little researchers who are interesting in using artificial intelligence in flow meter research.

The notification will be very useful to make correction to the error in meter reading. The faster the notification, the faster the error correction will be. When the notification has warned the system that the error has occurred, a correction factor to the EVC can be done by re-inputting the value to the system.

5. Conclusion

Some challenges occurred in TFM still become complicated problems. Although it seems only as a little problem, however, its occurrence has affected the losses in customers and industries. Thus, some strategies should be built. A notification system is proposed in this paper. An intelligent system that can determine the occurrence of the error will be embedded to the system. By having this notification, a correction can be done earlier. It is hope that the earlier the correction, the more minimum losses would be.

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