Challenges in Turbine Flow Metering System: An Overview

Bunyamin¹, Nyayu Latifah Husni², Hasan Basri¹*, Irsyadi Yani¹

¹Mechanical Engineering Department, Faculty of Engineering, Universitas Sriwijaya
²Electrical Engineering Department, Politeknik Negeri Sriwijaya

* E-mail: hasan_basri@unsri.ac.id

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](image)

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.

| 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] |
|      | 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 | Simulation | [16] |
|      | Xin Jin | Mathematical modeling using AMESim | Could manage the high frequency oscillation | Simulation | [19] |
| 2015 | 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. Đžemić | 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
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].

\[
\frac{v_x}{\tan \beta} = \frac{N \tan \beta v_x}{2 \pi r}
\]

where $v_x$ is the axial velocity, $v_b$ is the blade velocity, $\beta$ is the blade angle, $N$ is the number of the blade, and $r$ is the radius of the blades.

| 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 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 contradictory 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 ($\nu$) [26].

$$\nu = \frac{\mu}{\rho}$$

where, $\nu$ is kinematic viscosity; $\mu$ is absolute viscosity; and $\rho$ 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):

$$Re = \frac{\rho \nu D}{\mu}$$

where, $\rho$ is density; $\nu$ is velocity; $D$ is diameter; and $\mu$ 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.

$$\frac{\partial \rho}{\partial t} + \nabla (\rho u_i) = 0 \tag{5}$$

$$\partial_t (\rho u_i) + \frac{\partial}{\partial x_j} (\rho u_i u_j) = \rho g_i + \frac{\partial \rho}{\partial x_i} \frac{\partial \tau_i}{\partial x_i} \tag{6}$$

$$\frac{\partial \alpha_v \rho_v}{\partial t} + \frac{\partial}{\partial x_j} (\alpha_v \rho_v u_j) = 5 \tag{7}$$

$$S = m^1 + m^- \tag{8}$$

Where:

$$m = m^+ + m^- = \left( \frac{2\xi}{2 - \xi} \right) \left( \frac{M}{2\pi R} \right)^{\frac{1}{2}} \left( \frac{P_2}{\sqrt{T}} - \frac{P}{\sqrt{T}} \right) \Lambda \tag{9}$$
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.

| 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.                                                 | [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.

| Trouble                                      | Possible Cause                                           | Remedy                                               |
|----------------------------------------------|----------------------------------------------------------|------------------------------------------------------|
| Meter indicates higher than actual flow rate | − Cavitation                                             | − Increase back pressure                             |
|                                              | − Debris on rotor support                                | − Clean meter                                        |
|                                              | − Build-up of foreign material on meter bore             | − Clean meter                                        |
|                                              | − Gas in liquid                                          | − Install gas eliminator ahead of meter              |
|                                              |                                                          |                                                      |
| Meter indicates lower than actual flow rate  | − Debris on rotor                                        | − Clean meter and add filter                         |
|                                              | − Worn bearing                                           | − Clean meter and add filter                         |
|                                              | − Viscosity higher than calibrated                       | − 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: \( V_{\text{flow}} = \frac{34042}{\text{flow}} \times 1000 \), to get the \( V_{\text{flow}} \) value of AGA7. The value of the \( dV_9 \) of AGA 7 was then compared to the \( dV_9 \) 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.

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 \( \text{flow} \), indicates that \( \text{flow} \), the value of \( \delta \), indicates that \( \delta \), and the value of \( \gamma \), indicates that \( \gamma \). 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.

\[ \text{Difference} = \frac{\text{EVC} - \text{Manual}}{\text{Manual}} \times 100\% \]

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

| No. | Time   | Turbine Stand Meter (m³) | Pressure (BarA) | Temperature (°C) | Meter Reading Manual (AGA 7) | EVC (m³) |
|-----|--------|--------------------------|-----------------|-----------------|-----------------------------|----------|
| 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)

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 m³, with pressure 3.3 BarG and temperature 30 °C (Figure 5, (b) and (c)), while the EVC showed the base volume 38.35 m³, with primary volume 465253.0 m³, pressure 4.2419 BarA, and temperature 29.98 °C. Number of bouncing accidents in 2016 and 2017 can be seen in Figure 6 (a) and (b).

Figure 5. The display of meter reading (a) turbine stand meter; (b) pressure; (c) Temperature (reprinted with permission of PT. PGN)
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.

Acknowledgement
This research is one of the Author's Master Degree projects. The authors would like to express their gratitude to PT. PGN “Perusahaan Gas Negara” for the opportunity to use the turbine meter calibration data obtained in Stasiun Metering Talang Duku.

References
[1] E. Schena, C. Massaroni, P. Saccomandi, and S. Cecchini, “Flow Measurement in Mechanical Ventilation: a review,” *Med. Eng. Phys.*, vol. 37.3, pp. 257–264, 2015.
[2] S. Guo, L. Sun, T. Zhang, W. Yang, and Z. Yang, “Analysis of Viscosity Effect on Turbine Flow-meter Performance Based on Experiments and CFD Simulations,” *Flow Meas. Instrum.*, 2013.
[3] T. Wang and R. Drive, “Coriolis flowmeters: a review of developments over the past 20 years, and an assessment of the state of the art and likely future directions,” vol. 44, no. 0, pp. 34–38, 2014.
[4] H. Ghassemi and H. F. Fasih, “Application of small size cavitating venturi as flow controller and flow meter,” *Flow Meas. Instrum.*, vol. 22, no. 5, pp. 406–412, 2011.

[5] O. E. E, “Offshore Gas Well Flow and Orifice Metering System: An Overview,” *Innovatative Energy Res.*, vol. 6, no. 2, pp. 2–5, 2017.

[6] H. Zhou, T. Ji, R. Wang, X. Ge, X. Tang, and S. Tang, “Multipath ultrasonic gas flow-meter based on multiple reference waves Multipath ultrasonic gas flow-meter based on multiple reference waves,” *Ultrasonics*, no. July, 2017.

[7] Y. Yuan and T. Zhang, “Research on the Dynamic Characteristics of a Turbine Flow Meter,” *Flow Meas. Instrum.*, 2017.

[8] G. C. and B. L. Z. Y Z HuangB S Zhang, “Cavitation performance simulation of turbine meter under different temperature water condition,” *Int. Symp. Cavitation Multiph. Flow (ISCM 2014).* *Mater. Sci. Eng.*, vol. 72, 2015.

[9] F. Cascetta and G. Rotondo, “Effects of Intermittent Flows on Turbine Gas Meters Accuracy,” *MEASUREMENT*, no. February, 2015.

[10] J. Yoder, “Flowmeter Spin,” *Flow Research*, 2012.

[11] J. Pei, Z. Su, and K. Zhang, “Using Numerical Simulation to Optimize the Design of Gas Turbine Flowmeter Sensor,” pp. 1910–1913, 2013.

[12] C. L. Tegtmeier, “Analysis of a Turbine Flow Meter Calibration Curve using CFD,” *53rd AIAA Aerosp. Sci. Meet. Am. Inst. Aeronaut. Astronaut.*, no. January, pp. 1–12, 2015.

[13] B. M. Menezes and B. D. Manager, “Calculating & Optimizing Repeatability of Natural Gas Flow Measurements,” *Tech. Note*, no. November, 2012.

[14] R. S. Figliola and D. E. Beasley, *Theory and Design for Mechanical Measurements*, 5th Editio. John Wiley & Sons, Inc., 2011.

[15] F. Frenzel, *Industrial flow measurement Basics and practice*. ABB Automation Products GmbH, 2011.

[16] P. W. Tang, “Pressure , Temperature , and Other Effects on Turbine Meter Gas Flow Measurement,” *Am. Sch. Gas Meas. Technol.*, vol. 3, no. September, 2015.

[17] P. W. Stoltenkamp, *Dynamics of turbine flow meters*. Technische Universiteit Eindhoven, 2007.

[18] Z. Sabooohi, S. Sorkhkhah, and H. Shakeri, “Developing a Model for Prediction of Helical Turbine Flowmeter Performance Using CFD,” *Flow Meas. Instrum.*, 2014.

[19] X. Jin, B. Wang, and Z. Ye, “Driving Solution Study of a Turbine Flowmeter Dynamic Calibration System,” *Int. Conf. Fluid Power Mechatronics*, 2015.

[20] Z. Gediminas and M. Eugenijus, “Influence of Gas and Liquid Viscosity on Turbine and Positive Displacement Meters Calibration,” *17th Int. Congr. Metrol.*, vol. 3, pp. 1–6, 2015.

[21] L. I. Dong-hui and X. U. Jing-yu, “Measurement of Oil-Water Flow Via the Correlation of Turbine Flow Meter, Gamma Ray Densitometry and Drift-Flux Model,” *J. Hydrodyn.*, vol. 27, no. 4, pp. 548–555, 2015.

[22] M. L. Ali, R. Ridoy, U. Barua, and M. B. Alamgir, “Design and Fabrication of a Turbine Flow Meter,” *J. Mod. Sci. Technol.*, vol. 4, no. 1, pp. 16–26, 2016.

[23] G. Suna, Z. Tao, and S. Lijun, “Blade Shape Optimization of Liquid Turbine Flow Sensor,” *Trans. Tianjin Univ.*, pp. 144–150, 2016.

[24] Z. Džemić, B. Širok, and B. Bizjan, “Turbine Flowmeter Response to Transitional Flow Regimes,” *Flow Meas. Instrum.*, 2017.

[25] C. B. Roger, *Flow Measurement, Handbook*. Cambridge University Press, 2005.

[26] A. Trigas, “Practical Aspects of Turbine Flow Meters Calibration and UVC Principles,” *TrigasFl GmbH*, pp. 1–7, 2008.

[27] T. for L. NEL, “Good Practice Guide The Calibration of Flow Meter,” *Natl. Meas. Syst.*

[28] S. KV, “Adaptive Calibration of Turbine Flow Measurement using ANN,” *Int. Symp. Adv. Comput. Commun.*, 2015.

[29] Omega, “Turbine Flow meter Manual Book.” [Online]. Available: https://www.omega.com/manuals/manualpdf/M4517.pdf.
[30] Galvanic, “Application Insight: Gas Micro Electronic Volume Corrector. Electronic Volume Correction in NG Custody Transfer & Distribution Applications,” Galvanic Appl. Sci. Inc., no. June, 2015.

[31] S. Nurmaini, S. Z. M. Hashim, A. Zarkasi, B. Tutuko, and A. Triadi, “Target Localization With Fuzzy-Swarm Behavior,” pp. 21–24, 2014.

[32] A. S. Handayani, T. Dewi, N. L. Husni, S. Nurmaini, and I. Yani, “Target tracking in mobile robot under uncertain environment using fuzzy logic controller,” Int. Conf. Electr. Eng. Comput. Sci. Informatics, vol. 2017-Decem, no. September, pp. 19–21, 2017.

[33] A. Pandey, R. K. Sonkar, K. K. Pandey, and D. R. Parhi, “Path Planning Navigation of Mobile Robot With Obstacles Avoidance Using Fuzzy Logic Controller,” 2014.

[34] M. S. Masmoudi, N. Kriechen, M. Masmoudi, and N. Derbel, “Fuzzy Logic Controllers Design For Omnidirectional Mobile Robot Navigation,” Appl. Soft Comput. J., 2016.

[35] H. Omrane, M. S. Masmoudi, and M. Masmoudi, “Fuzzy Logic Based Control for Autonomous Mobile,” vol. 2016, 2016.

[36] N. L. Husni and A. S. Handayani, “Odor Localization using Gas Sensor for Mobile Robot.”

[37] A. S. Member, N. Latifah, H. Member, S. N. Member, and I. Yani, “The Survey Paper: Formation Control For Swarm Robots.”