Deskripsi Artikel

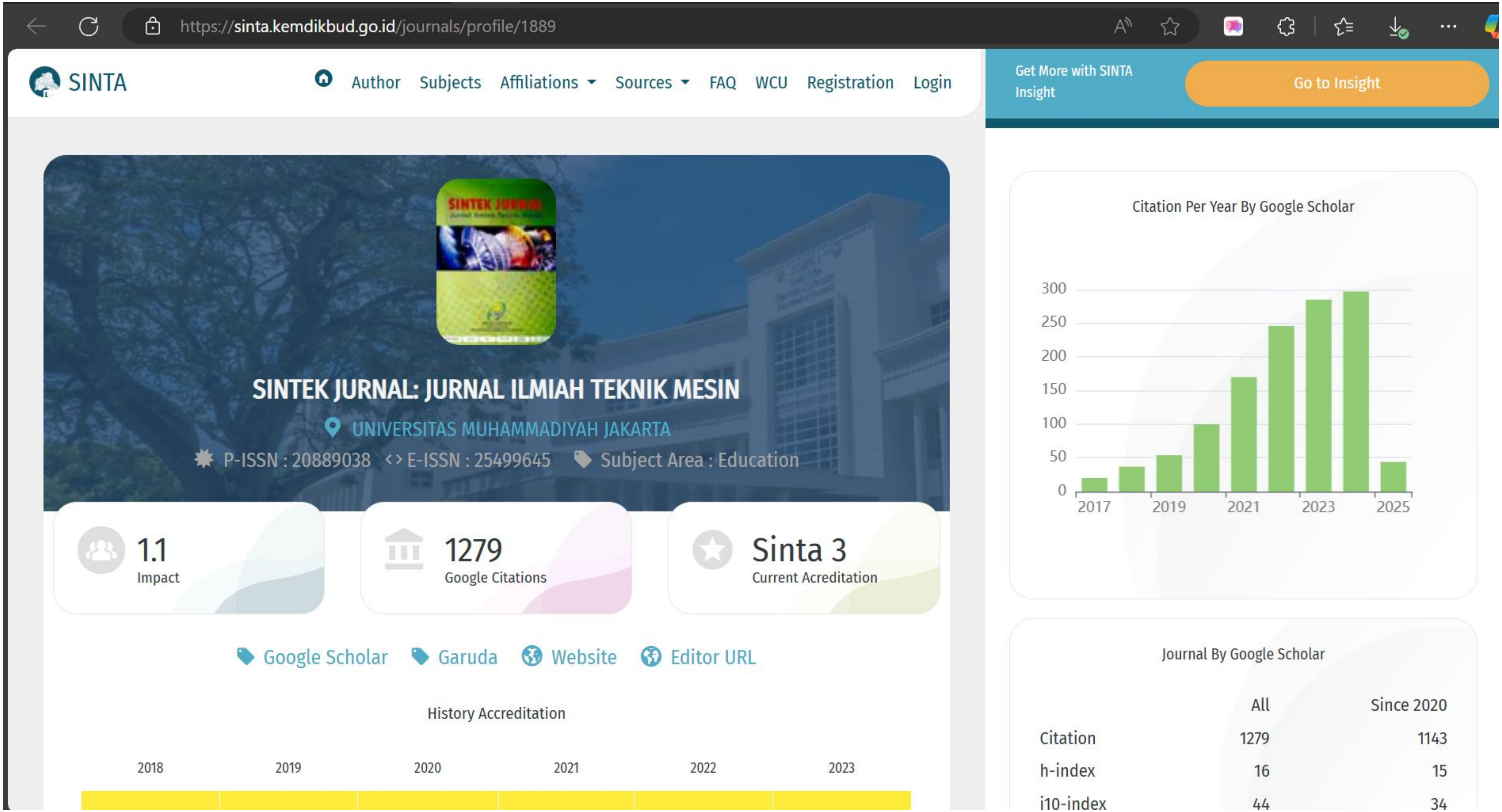
- Judul Jurnal : SINTEK JURNAL: Jurnal Ilmiah Teknik Mesin
- Volume Jurnal : Volume 14, Nomor 2, 2020
- Akreditasi : SINTA 3
- Judul Artikel : EFFECT OF CYLINDER SURFACE ROUGHNESS TO THE DISTANCE FORMATION OF VORTEX
- Penulis : **Oktarina Heriyani**, Dan Mugisidi, Irfan Hilmi
- Status Penulis : Kontributor

SINTEK JURNAL

Jurnal Ilmiah Teknik Mesin

JURUSAN TEKNIK MESIN
FAKULTAS TEKNIK
UNIVERSITAS MUHAMMADIYAH JAKARTA

SINTEK JURNAL | Vol.8 | No.2 | Hal. 1-38 | Jakarta Desember 2014 | ISSN 2088-9038


https://sinta.kemdikbud.go.id/journals/profile/1889
SINTA
Author
Subjects
Affiliations
Sources
FAQ
WCU
Registration
Login
Get More with SINTA Insight
Go to Insight
SINTEK JURNAL
SINTEK JURNAL: JURNAL ILMIAH TEKNIK MESIN
UNIVERSITAS MUHAMMADIYAH JAKARTA
P-ISSN : 20889038
E-ISSN : 25499645
Subject Area : Education
1.1
Impact
1279
Google Citations
Sinta 3
Current Acreditation
Google Scholar
Garuda
Website
Editor URL
History Accreditation
2018
2019
2020
2021
2022
2023
Citation Per Year By Google Scholar
300
250
200
150
100
50
0
2017
2019
2021
2023
2025
Journal By Google Scholar
All
Since 2020
Citation
1279
1143
h-index
16
15
i10-index
44
34

Editorial Team

https://jurnal.umj.ac.id/index.php/sintek/pages/view/Editorial%20Team

Daftar Isi

https://jurnal.umj.ac.id/index.php/sintek

SINTEK JURNAL: Jurnal Ilmiah Teknik Mesin
ISSN: 2088-9038, e-ISSN: 2549-9645
Homepage: http://jurnal.umj.ac.id/index.php/sintek

EFFECT OF CYLINDER SURFACE ROUGHNESS TO THE DISTANCE FORMATION OF VORTEX

Oktarina Heriyani[1,*], Dan Mugisidi[1], Irfan Hilmi[1]
[1]Department of Mechanical Engeenering, University of Muhammadiyah Prof. Dr. HAMKA
Tanah Merdeka Street No. 6, Kampung Rambutan Ciracas, Jakarta Timur, 13830

[*]E-mail: oktarina@uhamka.ac.id

Accepted: 20-04-2020 Revised: 11-11-2020 Approved: 01-12-2020

ABSTRACT

Reduction of cylinder surface resistance can be accomplished by modifying roughness. The surface roughness structure is one of the important parameters which greatly affects the flow of fluid through the cylinder surface. Fluid flow forms a vortex flow pattern with certain characteristics. Therefore, this study aims to analyze the characteristics and effects of fluid flow through the rough surface of the outer wall of the pipe with visualization using Particle Image Velocity (PIV). This research was conducted experimentally at the Faculty of Engineering, UHAMKA. The pipe surface roughness values varied were 0.648 µm and 1.699 µm. The length of the pipe used is 20 cm with a diameter of 2 inches. Measurements are made from the center of the pipe to a distance of 0.16 m. The results show that the surface roughness of the cylinder pipe affects the fluid flow characteristics where the formation of eddies is caused by the addition of the roughness value. The rougher the pipe surface is, the farther the vortex formation will be. The vortex formation closest to the pipe is a pipe with a roughness value of 0.648 µm at a distance of 0.04 m.

Keywords: *roughness; vortex; surface; pipe.*

1. INTRODUCTION

Technological developments to meet the needs and access to offshore resources continue to increase. One of them was the development of a cylindrical structure in the marine sector, namely piping [1]. Laying pipes on the seabed creates free spans along the structure due to scouring of the seabed. The pipe undergoes dynamic motion when exposed to a current such as vortex induced vibration (VIV) [2]. The vortex release creates an excitation force which causes the pillar structure to vibrate. If this vibration occurs continuously for a long time, it will cause damage due to fatigue [3].

Cylindrical surface roughness was one of the important parameters that significantly affects the flow through the cylinder based on the research results by Y. Gao et al. [4]. For example, the case occurred in a submarine pipeline. Increase in surface roughness due to growth of marine organisms over a period of time.

T. Zhou et al. explored the concept of controlling flow over circular cylinders to reduce shear and vibration forces caused by eddy flow [5]. Their exploration uses additional shape modifications, such as spiral grooves. M. Street et al. revealed the fact that hydrodynamic forces on a cylinder can arrive at its roughness [6]. The results of their study indicated that the drag reduction pathway was between 18% and 25%.

L. wang et all based on the results of their study said that the effect of surface roughness needs to be measured because it affects the performance of the fluid flow through it [7]. The results of their study reveal that the roughness parameters for changing the theoretical solutions of fluid flow and transport with modified cubic laws.

Accurate and efficient measurement of fluid flow velocity in experiments according to the study of M. Maceas et al., Is a PIV application [8]. This application is a non-invasive type of application that can provide an estimate of the flow rate in some area points up to 55%. J. Westerweel et all. stated that PIV can be reliable enough to reveal the structure of fluid flow [9].

Therefore, in this experiment using particle image velocity (PIV) as a result of visualization to determine the effect of cylinder surface roughness on the distance of vortex formation.

2. METHODS

This research method was carried out experimentally and simulated using Matlab and PIV. The test system design is as shown in **Figure 1**.

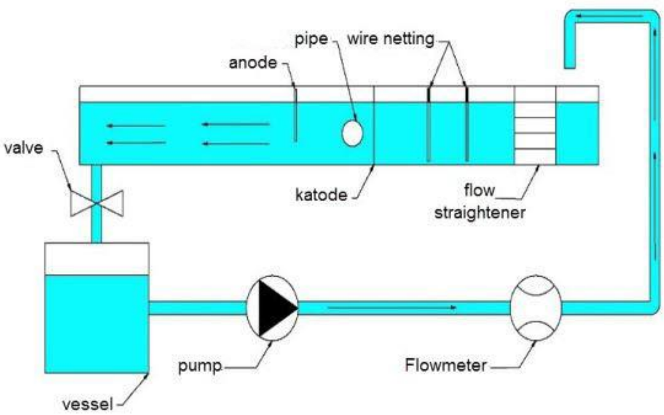


Figure 1. Testing System

Water flows through the flowbaker, cathode, anode, objects and flows back into the reservoir. In the container, 5 grams of sodium sulphate is added per liter which helps the electrolysis process. The addition of sodium sulphate at the time of visualization was 5 grams with a water capacity of 102.6 L based on the comparison of adding sodium sulfate to water for electrolysis of 0.05 grams / liter [11].

The tunnel geometry used in the test was modified from Dwita et al's research, as shown in **Figure 2**.

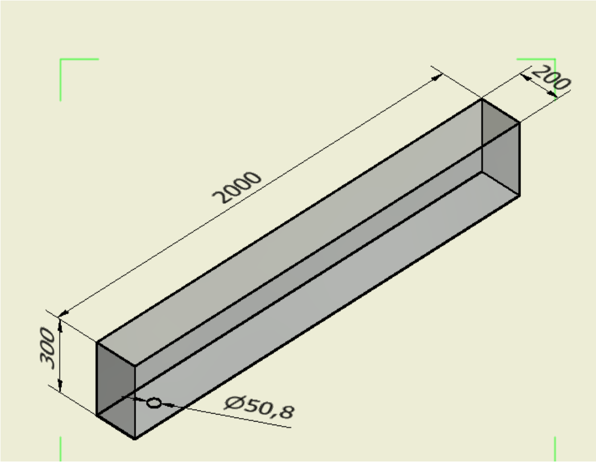


Figure 2. Tunnel Geometry [10]

The tunnel is made of acrylic material with a geometric size of 2000 mm x 200 mm x 300 mm. The objects used are pipes with a diameter of 2 inches and a pipe length of 20 cm.

The test was carried out by observing the visualization of hydrogen bubbles in the tunel flow. Flow velocity for variation of pipe surface roughness values (Ra) 0.648 µm and 1.699 µm resulted in a discharge of 79.8 L / minute. The results of visual data retrieval in the form of images are processed using the particle image velocity (PIV) application.

3. RESULTS AND DISCUSSION

The results of this study are influenced by the roughness value that is passed through the fluid flow with the Reynold Number (Re) parameter and the level of sodium sulphate in the water. Based on data processing using PIVlab software from MATLAB 2017 to analyze the movement of fluid flow through the pipe, a visualization of the comparison of vector directions is obtained, such as **Figure 3** and **Figure 4**.

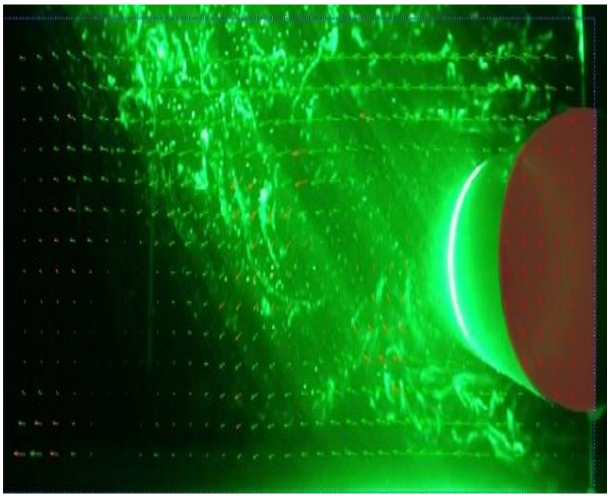


Figure 3. Vector directions on pipe surface roughness (Ra = 0.468 µm).

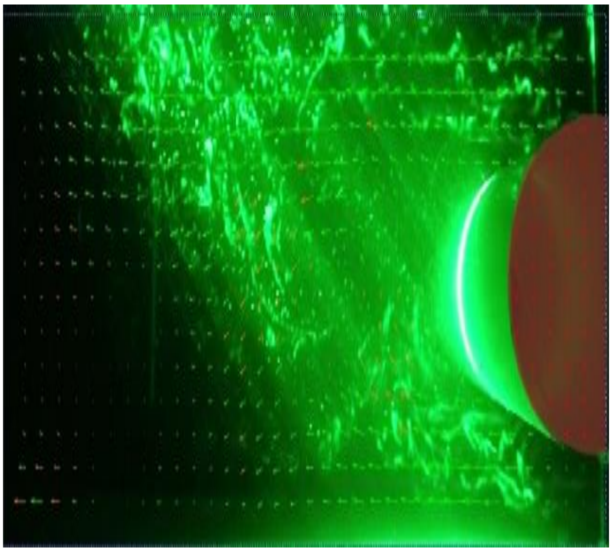


Figure 4. Vector directions on pipe surface roughness (Ra = 1.699 µm).

Figures 3 and 4 show that the direction of the vectors formed is similar to the vortex formation process. On the rough surface of Figure 4, the vortex is formed with a shorter distance than the vortex in Figure 3. This is due to the influence of buoyancy [12].

On a rough surface pipe with a value of Ra 0.648 µm it produces a vortex at the bottom with a distance of 0.05 m and the vortex at the top has a distance of 0.09 m from the center of the cylinder pipe, as shown in **Figure 5**.

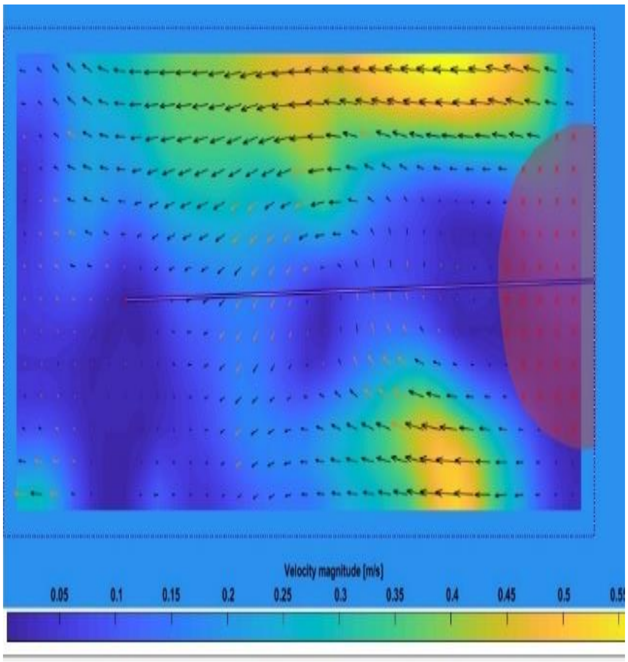


Figure 5. Velocity magnitude of rough surface pipe with Ra value of 0.648 µm.

Measurement from the center of the cylinder pipe to a distance of 0.16 m shows that the highest velocity profile is shown at 0.1 m / s and the lowest velocity is 0.02 m / s as shown in **Figure 6**.

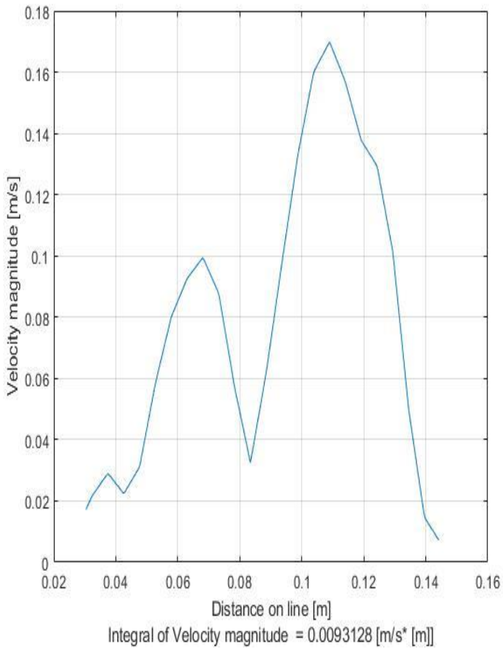


Figure 6. Graph of velocity magnitude on a pipe with Ra 0.648 µm.

The rough surface pipe with a Ra value of 1.699μm produces a vortex with a distance of 0.07 m at the bottom and the vortex at the top has a distance of 0.12 m from the center point of the cylinder pipe, as shown in **Figure 7**.

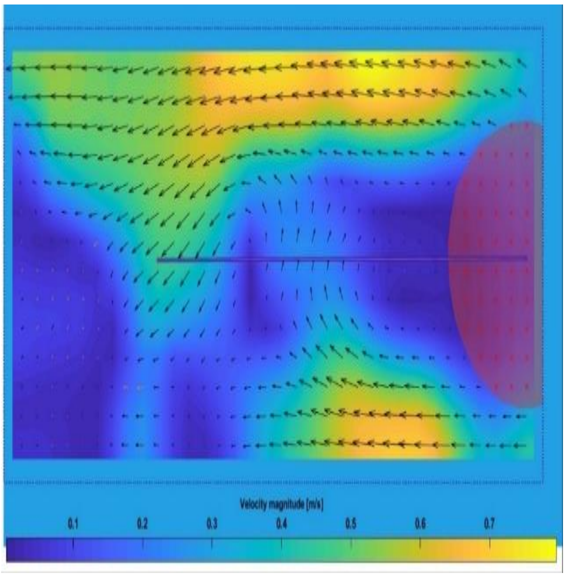


Figure 7. Velocity magnitude of rough surface pipe with ra value of 1.699 μm

The measurement from the center of the cylinder pipe to a distance of 0.16 m shows that the highest velocity characteristics are shown at 0.45 m / s and the lowest speed is 0.02 m / s, as shown in **Figure 8**.

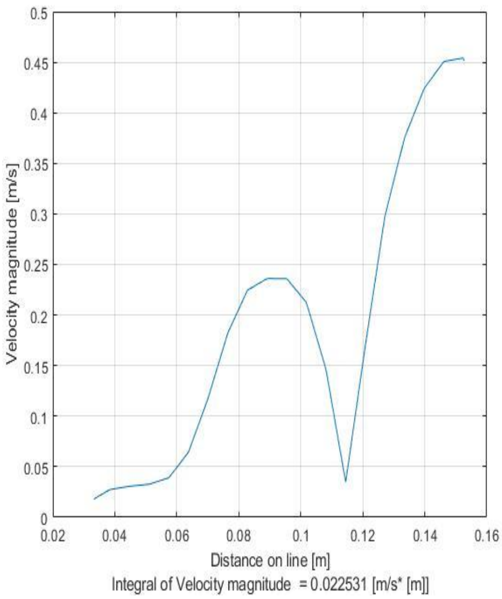


Figure 8. Graph of velocity magnitude on a pipe with Ra 1.699 μm

Based on **Figures 3**, **4**, **5**, and **7**, it can be seen that the vortex occurs at the top and bottom of the pipe surface. The closest vortex formation occurs at the bottom than at the top. The proximity is measured from the center of the pipe to a distance of 0.16 m. The closest vortex distance formed on the pipe surface roughness Ra 0.648 μm compared to Ra 1.699 μm.

The increase in the surface roughness of the pipe increases the distance the vortex forms. Fluid flow passing through pipe roughness is affected by pipe surface roughness. The process of splitting the vortex flow will form small vortices that are very clear at the bottom of the pipe so that the recirculation zone distance increases. Y. Li et all. explained the inverse relationship between the friction factor and Reynolds number in the coarse pipe still persisting in the coarse pipe, regardless of the rib height [13]. K. Luo found that particles with a greater number of Stokes showed a more distinct deposition in the inner region and less deposition of objects due to the presence of coarse elements [14].

4. CONCLUSION

The increase in surface roughness in the cylinder pipe can affect the flow of water through the cylinder pipe, the process of breaking the vortex flow is formed into a small vortex vortex which is very clearly visible at the bottom of the cylinder pipe, resulting in an increase in the recirculation zone distance. The formation of the lower vortex closest to the pipe is a pipe with a roughness of 0.648 μm at a distance of 0.05 m.

ACKNOWLEDGMENTS

The research team would like to thank LEMLIT UHAMKA for funding this research with contract number 667 / F.03.07 / 2019 so that it went smoothly. Do not forget to also thank the Faculty of Engineering, UHAMKA for facilitating the laboratory infrastructure so that this research can be carried out.

REFERENCES

[1] B. Zhou, X. Wang, W. M. Gho, and S. K. Tan, “Force and flow characteristics of a circular cylinder with uniform surface roughness at subcritical Reynolds numbers,” *Appl. Ocean Res.*, vol. 49, pp. 20–26, 2015, doi:

10.1016/j.apor.2014.06.002.
[2] C. H. K. Williamson and R. Govardhan, "Vortex-induced vibrations," *Annu. Rev. Fluid Mech.*, 2004, doi: 10.1146/annurev.fluid.36.050802.122128.
[3] B. M. Sumer and J. Fredsøe, *Hydrodynamics around cylindrical strucures*, vol. 26. 2006.
[4] Y. Gao, L. Liu, L. Zou, Z. Zhang, and B. Yang, "Effect of surface roughness on vortex-induced vibrations of a freely vibrating cylinder near a stationary plane wall," *Ocean Eng.*, 2020, doi: 10.1016/j.oceaneng.2019.106837.
[5] T. Zhou, S. F. M. Razali, Z. Hao, and L. Cheng, "On the study of vortex-induced vibration of a cylinder with helical strakes," *J. Fluids Struct.*, vol. 27, no. 7, pp. 903–917, 2011, doi: 10.1016/j.jfluidstructs.2011.04.014.
[6] M. Street and G. Glasgow, "Drag Reduction of Deepwater Risers by the Use of Helical Grooves," pp. 1–5, 2017.
[7] L. Wang, M. B. Cardenas, D. T. Slottke, R. A. Ketcham, and J. M. Sharp, "Modification of the Local Cubic Law of fracture flow for weak inertia, tortuosity, and roughness," *Water Resour. Res.*, 2015, doi: 10.1002/2014WR015815.
[8] M.MaceasbA.F.OsoriobF.Bolanosa, "A methodology for improving both performance and measurement errors in PIV," *Flow Meas. Instrum.*, 2020.
[9] J. Westerweel, G. E. Elsinga, and R. J. Adrian, "Particle image velocimetry for complex and turbulent flows," *Annual Review of Fluid Mechanics*. 2013, doi: 10.1146/annurev-fluid-120710-101204.
[10] I. T. Dwita, "Aplikasi Gelembung Hidrogen untuk Analisa Dinamika Fluida pada Bola, Bola Golf dan Orifis di Aliran Fluida."
[11] D. R. Sabatino, T. J. Praisner, C. R. Smith, and C. V. Seal, "Hydrogen Bubble Visualization," in *Flow Visualization*, Imperial College Press, 2012, pp. 27–45.
[12] M. Bazargan, D. Fraser, and V. Chatoorgan, "Effect of buoyancy on heat transfer in supercritical water flow in a horizontal round tube," *J. Heat Transfer*, vol. 127, no. 8, pp. 897–902, 2005, doi: 10.1115/1.1929787.
[13] Y. Liu, J. Li, and A. J. Smits, "Roughness effects in laminar channel flow," *J. Fluid Mech.*, vol. 876, pp. 1129–1145, 2019, doi: 10.1017/jfm.2019.603.
[14] K. Luo, H. Zhang, M. Luo, X. Wu, and J. Fan, "Effects of solid particles and wall roughness on turbulent boundary layer in a two-phase horizontal channel flow," *Powder Technol.*, vol. 353, pp. 48–56, 2019, doi: 10.1016/j.powtec.2019.05.009.

Oktarina Heriyani Uploaded By Lutfan Zulwaqar

Oktarina Heriyani - EFFECT OF CYLINDER SURFACE ROUGHNESS TO THE DISTANCE FORMATION OF VORTEX

18% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

Filtered from the Report

- Bibliography

Exclusions

- 33 Excluded Sources
- 6 Excluded Matches

Match Groups

12 Not Cited or Quoted 15%
Matches with neither in-text citation nor quotation marks

3 Missing Quotations 3%
Matches that are still very similar to source material

0 Missing Citation 0%
Matches that have quotation marks, but no in-text citation

0 Cited and Quoted 0%
Matches with in-text citation present, but no quotation marks

Top Sources

1% Internet sources
3% Publications
15% Submitted works (Student Papers)

Integrity Flags

0 Integrity Flags for Review

No suspicious text manipulations found.

Our system's algorithms look deeply at a document for any inconsistencies that would set it apart from a normal submission. If we notice something strange, we flag it for you to review.

A Flag is not necessarily an indicator of a problem. However, we'd recommend you focus your attention there for further review.

Match Groups

- **12** Not Cited or Quoted 15%
  Matches with neither in-text citation nor quotation marks
- **3** Missing Quotations 3%
  Matches that are still very similar to source material
- **0** Missing Citation 0%
  Matches that have quotation marks, but no in-text citation
- **0** Cited and Quoted 0%
  Matches with in-text citation present, but no quotation marks

Top Sources

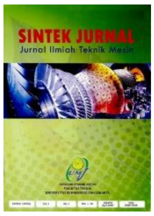
1% Internet sources
3% Publications
15% Submitted works (Student Papers)

Top Sources

The sources with the highest number of matches within the submission. Overlapping sources will not be displayed.

1	Student papers	**Universitas Sultan Ageng Tirtayasa**	**15%**
2	Publication	**Kun Luo, Hancong Zhang, Mingbo Luo, Xuecheng Wu, Jianren Fan. "Effects of soli...**	**1%**
3	Publication	**Bo Zhou, Xikun Wang, Wie Min Gho, Soon Keat Tan. "Force and flow characteristic...**	**<1%**
4	Internet	**accedacris.ulpgc.es**	**<1%**
5	Internet	**repository.kaust.edu.sa**	**<1%**

SINTEK JURNAL: Jurnal Ilmiah Teknik Mesin
ISSN: 2088-9038, e-ISSN: 2549-9645
Homepage: http://jurnal.umj.ac.id/index.php/sintek



EFFECT OF CYLINDER SURFACE ROUGHNESS TO THE DISTANCE FORMATION OF VORTEX

Oktarina Heriyani[1,*], Dan Mugisidi[1], Irfan Hilmi[1]
[1]Department of Mechanical Engeenering, University of Muhammadiyah Prof. Dr. HAMKA
Tanah Merdeka Street No. 6, Kampung Rambutan Ciracas, Jakarta Timur, 13830

[*]E-mail: oktarina@uhamka.ac.id

Accepted: 20-04-2020 Revised: 11-11-2020 Approved: 01-12-2020

ABSTRACT

Reduction of cylinder surface resistance can be accomplished by modifying roughness. The surface roughness structure is one of the important parameters which greatly affects the flow of fluid through the cylinder surface. Fluid flow forms a vortex flow pattern with certain characteristics. Therefore, this study aims to analyze the characteristics and effects of fluid flow through the rough surface of the outer wall of the pipe with visualization using Particle Image Velocity (PIV). This research was conducted experimentally at the Faculty of Engineering, UHAMKA. The pipe surface roughness values varied were 0.648 µm and 1.699 µm. The length of the pipe used is 20 cm with a diameter of 2 inches. Measurements are made from the center of the pipe to a distance of 0.16 m. The results show that the surface roughness of the cylinder pipe affects the fluid flow characteristics where the formation of eddies is caused by the addition of the roughness value. The rougher the pipe surface is, the farther the vortex formation will be. The vortex formation closest to the pipe is a pipe with a roughness value of 0.648 µm at a distance of 0.04 m.

Keywords: *roughness; vortex; surface; pipe.*

1. INTRODUCTION

Technological developments to meet the needs and access to offshore resources continue to increase. One of them was the development of a cylindrical structure in the marine sector, namely piping [1]. Laying pipes on the seabed creates free spans along the structure due to scouring of the seabed. The pipe undergoes dynamic motion when exposed to a current such as vortex induced vibration (VIV) [2]. The vortex release creates an excitation force which causes the pillar structure to vibrate. If this vibration occurs continuously for a long time, it will cause damage due to fatigue [3].

Cylindrical surface roughness was one of the important parameters that significantly affects the flow through the cylinder based on the research results by Y. Gao et al. [4]. For example, the case occurred in a submarine pipeline. Increase in surface roughness due to growth of marine organisms over a period of time.

T. Zhou et al. explored the concept of controlling flow over circular cylinders to reduce shear and vibration forces caused by eddy flow [5]. Their exploration uses additional shape modifications, such as spiral grooves. M. Street et al. revealed the fact that hydrodynamic forces on a cylinder can arrive at its roughness [6]. The results of their study indicated that the drag reduction pathway was between 18% and 25%.

L. wang et all based on the results of their study said that the effect of surface roughness needs to be measured because it affects the performance of the fluid flow through it [7]. The results of their study reveal that the roughness parameters for changing the theoretical solutions of fluid flow and transport with modified cubic laws.

Accurate and efficient measurement of fluid flow velocity in experiments according to the study of M. Maceas et al., Is a PIV application [8]. This application is a non-invasive type of application that can provide an estimate of the flow rate in some area points up to 55%. J. Westerweel et all. stated that PIV can be reliable enough to reveal the structure of fluid flow [9].

Therefore, in this experiment using particle image velocity (PIV) as a result of visualization to determine the effect of cylinder surface roughness on the distance of vortex formation.

2. METHODS

This research method was carried out experimentally and simulated using Matlab and PIV. The test system design is as shown in **Figure 1**.

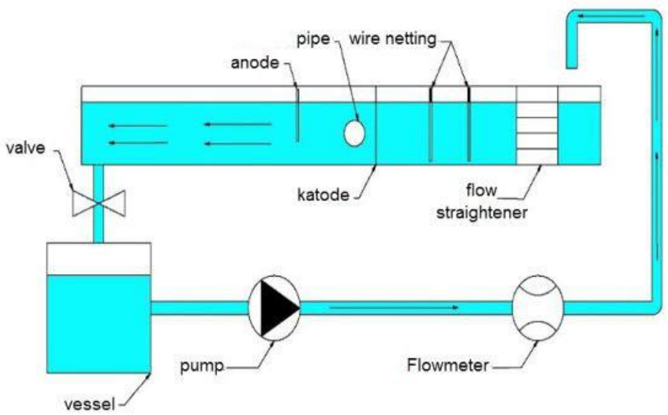


Figure 1. Testing System

Water flows through the flowbaker, cathode, anode, objects and flows back into the reservoir. In the container, 5 grams of sodium sulphate is added per liter which helps the electrolysis process. The addition of sodium sulphate at the time of visualization was 5 grams with a water capacity of 102.6 L based on the comparison of adding sodium sulfate to water for electrolysis of 0.05 grams / liter [11].

The tunnel geometry used in the test was modified from Dwita et al's research, as shown in **Figure 2**.

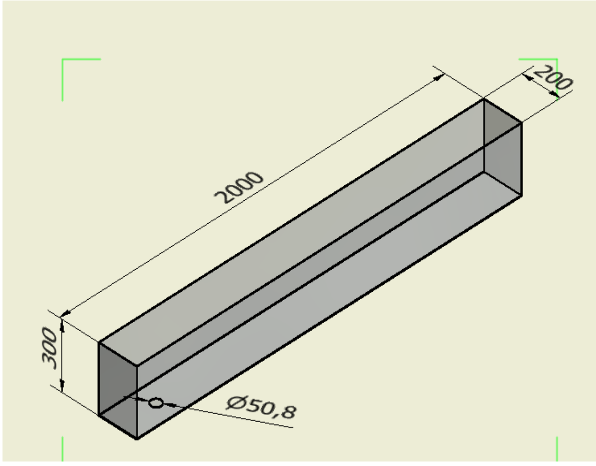


Figure 2. Tunnel Geometry [10]

The tunnel is made of acrylic material with a geometric size of 2000 mm x 200 mm x 300 mm. The objects used are pipes with a diameter of 2 inches and a pipe length of 20 cm.

The test was carried out by observing the visualization of hydrogen bubbles in the tunel flow. Flow velocity for variation of pipe surface roughness values (Ra) 0.648 µm and 1.699 µm resulted in a discharge of 79.8 L / minute. The results of visual data retrieval in the form of images are processed using the particle image velocity (PIV) application.

3. RESULTS AND DISCUSSION

The results of this study are influenced by the roughness value that is passed through the fluid flow with the Reynold Number (Re) parameter and the level of sodium sulphate in the water. Based on data processing using PIVlab software from MATLAB 2017 to analyze the movement of fluid flow through the pipe, a visualization of the comparison of vector directions is obtained, such as **Figure 3** and **Figure 4**.

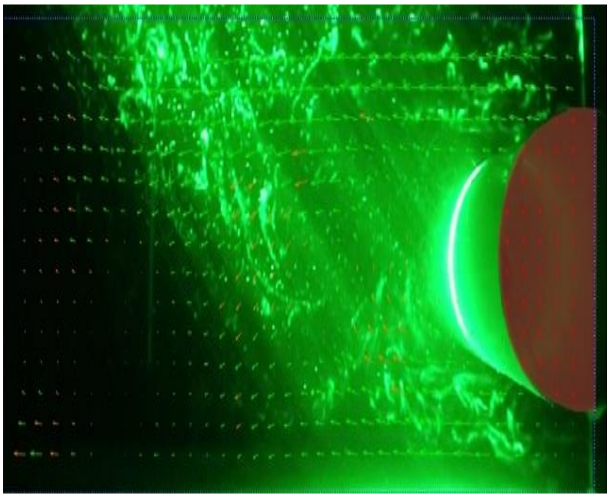


Figure 3. Vector directions on pipe surface roughness (Ra = 0.468 µm).

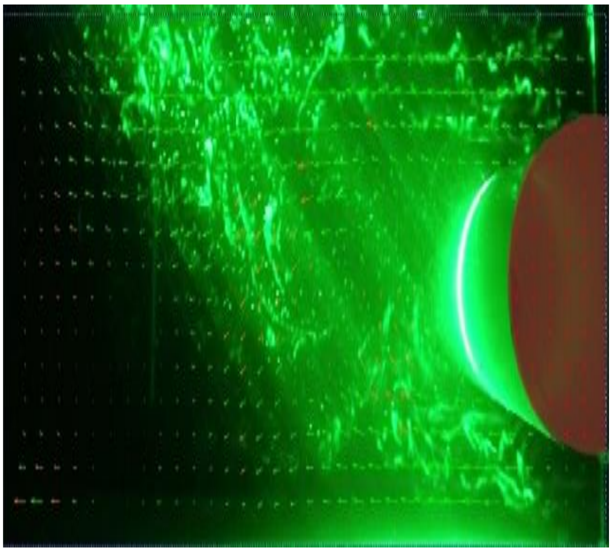


Figure 4. Vector directions on pipe surface roughness (Ra = 1.699 µm).

Figures 3 and 4 show that the direction of the vectors formed is similar to the vortex formation process. On the rough surface of Figure 4, the vortex is formed with a shorter distance than the vortex in Figure 3. This is due to the influence of buoyancy [12].

On a rough surface pipe with a value of Ra 0.648 µm it produces a vortex at the bottom with a distance of 0.05 m and the vortex at the top has a distance of 0.09 m from the center of the cylinder pipe, as shown in **Figure 5**.

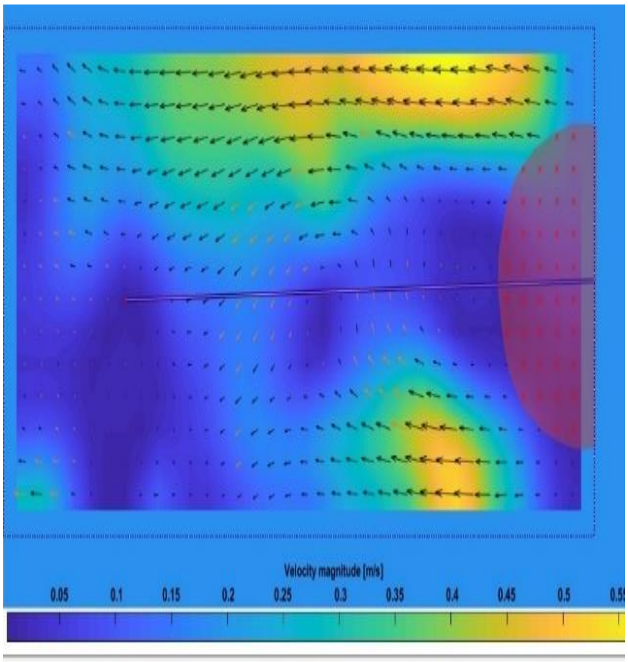


Figure 5. Velocity magnitude of rough surface pipe with Ra value of 0.648 µm.

Measurement from the center of the cylinder pipe to a distance of 0.16 m shows that the highest velocity profile is shown at 0.1 m / s and the lowest velocity is 0.02 m / s as shown in **Figure 6**.

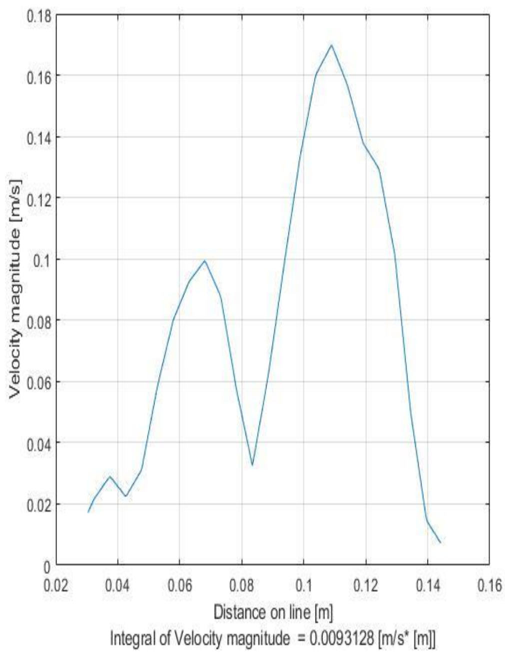


Figure 6. Graph of velocity magnitude on a pipe with Ra 0.648 µm.

The rough surface pipe with a Ra value of 1.699µm produces a vortex with a distance of 0.07 m at the bottom and the vortex at the top has a distance of 0.12 m from the center point of the cylinder pipe, as shown in **Figure 7**.

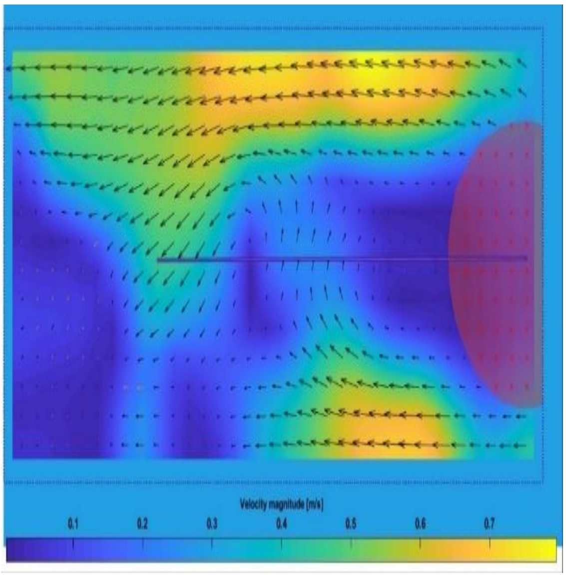


Figure 7. Velocity magnitude of rough surface pipe with ra value of 1.699 µm

The measurement from the center of the cylinder pipe to a distance of 0.16 m shows that the highest velocity characteristics are shown at 0.45 m / s and the lowest speed is 0.02 m / s, as shown in **Figure 8**.

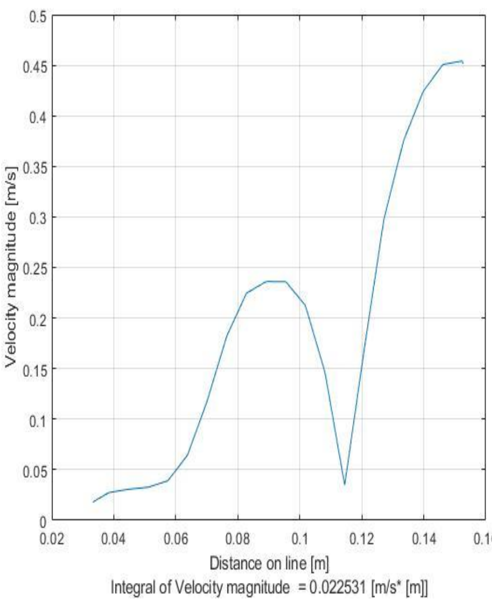


Figure 8. Graph of velocity magnitude on a pipe with Ra 1.699 µm

Based on **Figures 3**, **4**, **5**, and **7**, it can be seen that the vortex occurs at the top and bottom of the pipe surface. The closest vortex formation occurs at the bottom than at the top. The proximity is measured from the center of the pipe to a distance of 0.16 m. The closest vortex distance formed on the pipe surface roughness Ra 0.648 µm compared to Ra 1.699 µm.

The increase in the surface roughness of the pipe increases the distance the vortex forms. Fluid flow passing through pipe roughness is affected by pipe surface roughness. The process of splitting the vortex flow will form small vortices that are very clear at the bottom of the pipe so that the recirculation zone distance increases. Y. Li et all. explained the inverse relationship between the friction factor and Reynolds number in the coarse pipe still persisting in the coarse pipe, regardless of the rib height [13]. K. Luo found that particles with a greater number of Stokes showed a more distinct deposition in the inner region and less deposition of objects due to the presence of coarse elements [14].

4. CONCLUSION

The increase in surface roughness in the cylinder pipe can affect the flow of water through the cylinder pipe, the process of breaking the vortex flow is formed into a small vortex vortex which is very clearly visible at the bottom of the cylinder pipe, resulting in an increase in the recirculation zone distance. The formation of the lower vortex closest to the pipe is a pipe with a roughness of 0.648 µm at a distance of 0.05 m.

ACKNOWLEDGMENTS

The research team would like to thank LEMLIT UHAMKA for funding this research with contract number 667 / F.03.07 / 2019 so that it went smoothly. Do not forget to also thank the Faculty of Engineering, UHAMKA for facilitating the laboratory infrastructure so that this research can be carried out.

REFERENCES

[1] B. Zhou, X. Wang, W. M. Gho, and S. K. Tan, "Force and flow characteristics of a circular cylinder with uniform surface roughness at subcritical Reynolds numbers," *Appl. Ocean Res.*, vol. 49, pp. 20–26, 2015, doi:

10.1016/j.apor.2014.06.002.
[2] C. H. K. Williamson and R. Govardhan, "Vortex-induced vibrations," *Annu. Rev. Fluid Mech.*, 2004, doi: 10.1146/annurev.fluid.36.050802.122128.
[3] B. M. Sumer and J. Fredsøe, *Hydrodynamics around cylindrical strucures*, vol. 26. 2006.
[4] Y. Gao, L. Liu, L. Zou, Z. Zhang, and B. Yang, "Effect of surface roughness on vortex-induced vibrations of a freely vibrating cylinder near a stationary plane wall," *Ocean Eng.*, 2020, doi: 10.1016/j.oceaneng.2019.106837.
[5] T. Zhou, S. F. M. Razali, Z. Hao, and L. Cheng, "On the study of vortex-induced vibration of a cylinder with helical strakes," *J. Fluids Struct.*, vol. 27, no. 7, pp. 903–917, 2011, doi: 10.1016/j.jfluidstructs.2011.04.014.
[6] M. Street and G. Glasgow, "Drag Reduction of Deepwater Risers by the Use of Helical Grooves," pp. 1–5, 2017.
[7] L. Wang, M. B. Cardenas, D. T. Slottke, R. A. Ketcham, and J. M. Sharp, "Modification of the Local Cubic Law of fracture flow for weak inertia, tortuosity, and roughness," *Water Resour. Res.*, 2015, doi: 10.1002/2014WR015815.
[8] M.MaceasbA.F.OsoriobF.Bolanosa, "A methodology for improving both performance and measurement errors in PIV," *Flow Meas. Instrum.*, 2020.
[9] J. Westerweel, G. E. Elsinga, and R. J. Adrian, "Particle image velocimetry for complex and turbulent flows," *Annual Review of Fluid Mechanics*. 2013, doi: 10.1146/annurev-fluid-120710-101204.
[10] I. T. Dwita, "Aplikasi Gelembung Hidrogen untuk Analisa Dinamika Fluida pada Bola, Bola Golf dan Orifis di Aliran Fluida."
[11] D. R. Sabatino, T. J. Praisner, C. R. Smith, and C. V. Seal, "Hydrogen Bubble Visualization," in *Flow Visualization*, Imperial College Press, 2012, pp. 27–45.
[12] M. Bazargan, D. Fraser, and V. Chatoorgan, "Effect of buoyancy on heat transfer in supercritical water flow in a horizontal round tube," *J. Heat Transfer*, vol. 127, no. 8, pp. 897–902, 2005, doi: 10.1115/1.1929787.
[13] Y. Liu, J. Li, and A. J. Smits, "Roughness effects in laminar channel flow," *J. Fluid Mech.*, vol. 876, pp. 1129–1145, 2019, doi: 10.1017/jfm.2019.603.
[14] K. Luo, H. Zhang, M. Luo, X. Wu, and J. Fan, "Effects of solid particles and wall roughness on turbulent boundary layer in a two-phase horizontal channel flow," *Powder Technol.*, vol. 353, pp. 48–56, 2019, doi: 10.1016/j.powtec.2019.05.009.