SSRG International Journal of Recent Engineering Science
ISSN: 2349–7157 / https://doi.org/10.14445/23497157/IJRES-V11I4P107

Volume 11 Issue 4, 46-52, Jul-Aug 2024

Original Article

Modeling the Critical Velocity of Cement Slurry with Changes in the Size of a Wellbore

William Ejuvweyerome Odiete

[1]*Department of Petroleum Engineering, Delta State University, Abraka, Delta State, Nigeria.*

Corresponding Author : williamodiete@gmail.com

Received: 22 May 2024 Revised: 30 June 2024 Accepted: 21 July 2024 Published: 09 August 2024

Abstract *- This work investigated the variation of the critical velocity of cement slurry with changes in the size (diameter) of a wellbore during the cementing of oil and gas wells. Pipes of different internal diameters were used to represent different sections of a wellbore to simulate variation in the size of the wellbore. This also implies simulating wellbores of different sizes (diameters). Results revealed that the critical velocity of cement slurry increased with an increase in the size of the wellbore. Results showed that the critical velocity of cement slurry decreased with a reduction in the size of the wellbore. Mathematical models generated to predict the variation of the critical velocity of the cement slurry with open-hole (wellbore) size have a very high correlation coefficient (R^2), confirming that they can be used with a very high degree of certainty to predict the variation of the critical velocity of cement slurry with the size of a wellbore. Application of the results of this study will improve cementing job design and execution in the oil and gas industry.*

Keywords *- Cementing job design, Design optimization, Flow regime, Mud removal, Well cementing.*

1. Introduction

The critical velocity of a flowing fluid is the velocity corresponding to the critical Reynolds number. It determines when the flow changes from laminar to turbulent flow. The velocity profile of turbulent flow achieves better mud removal than the velocity profile of laminar flow. Vedantu (2024) stated that critical velocity is the velocity at which the flow of a fluid changes from laminar flow to turbulent flow. Pegasus Vertex Inc. (2024) stated that the critical velocity of a flowing fluid is the speed at which the flow changes from laminar to turbulent flow.

Primary cementing is the process of mixing cement slurry and pumping it through a casing and/or annulus into the zone of interest in the wellbore (Petrowiki 2024). Wang et al. (2022) stated that the annulus has a wide and narrow clearance due to casing eccentricity in the cementing process and due to the eccentricity of casing in the process of cementing. Petrowiki (2021) stated that remedial cementing is a process usually undertaken to solve problems associated with a primary cementing job. Foroushan et al. (2021) reported that effective displacement of cement slurry leads to high-quality cementing jobs that provide good zonal isolation and strong bonding of cement to casing and formation.

During primary cementing or remedial cementing job designs, the cement slurry is designed to be pumped in a particular flow regime – laminar flow or preferably turbulent flow if the formation fracture gradient is favorable. This implies that the displacement rate of the cement slurry into the zone of interest must not fall below a particular minimum to enable the cement slurry to remain in its design flow regime throughout the cementing job. When the displacement rate falls below that minimum, the flow regime of the cement slurry will change, e.g., from turbulent flow to laminar flow.

There is also the possibility of contamination of the cement slurry with the mud in the hole and with the displacing mud, both of which can change the rheology of the cement slurry and cause its flow to change from turbulent to laminar flow. Avoiding this undesirable incident requires pumping pre-flushes (chemical washes and spacer) ahead of the cement slurry to prevent contact between the mud and the cement slurry.

The densities of the pre-flushes are usually designed to be less than the density of the cement slurry and they are easier to pump in turbulent flow, especially chemical washes, to enhance mud removal ahead of the cement slurry. Water is usually pumped behind the cement slurry to prevent contact between the displacing mud and the cement slurry. Petrowiki (2021) reported that excellent planning and risk management are required to achieve successful remedial cementing.

Wellbore irregularities result from a combination of geology and or drilling/completion operations (Renteria et al., 2022). The change in the critical velocity of cement slurry with variation in the size of the wellbore during the primary cementing of oil and gas wells is the focus of this work. The critical velocity of a fluid (e.g., cement slurry) changes with the size of the pipe or open hole or annulus through which it is flowing. This implies that as every section of a wellbore is not usually uniform in size, so the critical velocity of the cement slurry changes from one section to another along the wellbore. For example, there could be an increase in the size (or diameter) of any sections of a wellbore due to wash-outs or a decrease in the size of any section of a wellbore due to swelling clays. Wang et al. (2022) stated that the flow resistance of fluid in the wide section of the annulus is less than that in the narrow section of the annulus, and it can cause delayed flow or no flow in the narrow section.

Therefore, knowledge of the variation of the critical velocity of cement slurry with open-hole size will enable the cementing job design engineer to optimize the primary cementing job design. It will enable the cementing engineer to design a cement slurry whose rheology will enable it to be displaced at the design flow regime from the surface to the zone of interest in the wellbore during the primary cementing job. Furthermore, the critical velocity of cement slurry changes with temperature. Therefore, it is necessary to be acquainted with how the critical velocity of cement slurry changes with open-hole size at different temperatures. Odiete and Iyagba (2015) reported that the critical velocity of cement slurry increases with temperature. Yang et al. (2022) stated that pumping various fluids into a wellbore causes major changes in fluid flow compared with pumping a single fluid.

Modeling the variation of the critical velocity of the cement slurry with open-hole size will enable the prediction of the critical velocity at any section of the hole where there are changes in the size of the wellbore. It will enable cementing engineers to optimize cementing job designs. This is particularly important in cases of emergency especially where the cementing design and evaluation software fails or when the computer malfunctions.

2. Materials and Methods

The cement slurry was prepared according to API Spec 10B (API 1997) and conditioned in the atmospheric consistometer for 20 minutes at a test temperature of 27ºC, and the rheology was conducted using a Chan-35 Rheometer. Fresh cement slurries were prepared, and the rheology was conducted at the other test temperatures of 38ºC, 49ºC, 60ºC and 71ºC. The density and viscosity of the cement slurry at each test temperature were measured.

Trenchlesspedia (2024) stated that the critical velocity of a fluid flowing through a pipe is given by

$$V_c = \frac{Re_c \mu}{\rho D}$$

Where, D = internal diameter of pipe, ρ = density of fluid, μ = viscosity of fluid, Re_c = critical Reynolds number, V_c = critical velocity

The critical velocity of the cement slurry was calculated using a critical Reynolds number of 3000 and pipes of different internal diameters of 7" (2.133495885m), 10"(3.047851265m), 13" (3.962206644m), 17" (5.18134715m) and 20" (6.09570253m) which were used to simulate different sections of the wellbore. This also implies simulating wellbores of different sizes (diameters). Mathematical models for predicting the critical velocity of the cement slurry with wellbore size were generated using Microsoft Excel.

3. Results and Discussion

The variation and modeling of the critical velocity of the cement slurry at each test temperature with wellbore (open-hole) size are represented in Figures 1(A and B) to 5 (A and B). Each Figure consists of a bar chart and a graph. The bar chart depicts the variation of the critical velocity of the cement slurry with wellbore size (diameter). Each graph depicts the mathematical modeling of the critical velocity of the cement slurry with wellbore size.

The variation and modeling of the critical velocity of the cement slurry at 27ºC with wellbore diameter (open-hole size) are shown in Figures 1A and 1B.

It is evident from the bar chart (Figure 1A) and the graph (Figure 1B) that the critical velocity of the cement slurry at the test temperature increased with wellbore (open-hole) size (diameter) and vice versa. The equation on the graph (Figure 1B) is the mathematical model for predicting the critical velocity with open-hole size at the test temperature of 27ºC.

The variation and modeling of the critical velocity of the cement slurry at 38ºC with open-hole size are presented in Figures 2A and 2B.

It is evident from the bar chart (Figure 2A) and the graph (Figure 2B) that the critical velocity of the cement slurry at the test temperature increased with open-hole size and vice versa. The equation on the graph (Figure 2B) is the mathematical model for predicting the critical velocity with open-hole size at the test temperature of 38ºC.

The variation and modeling of the critical velocity of the cement slurry with open-hole size at 49ºC are as presented in Figures 3A and 3B.

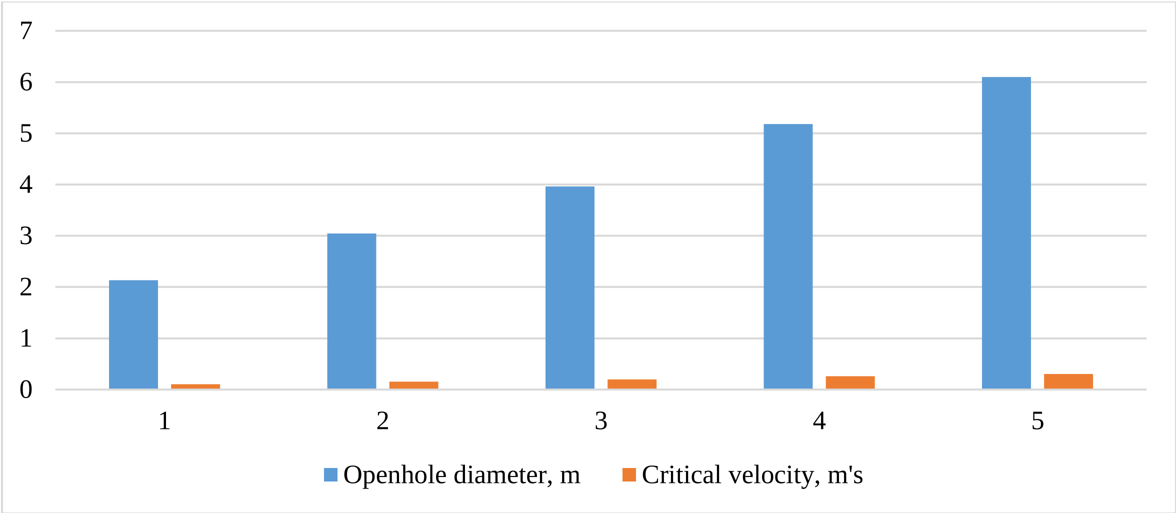

Fig. 1(A) Variation of critical velocity of the cement slurry at 27ºC with wellbore diameter

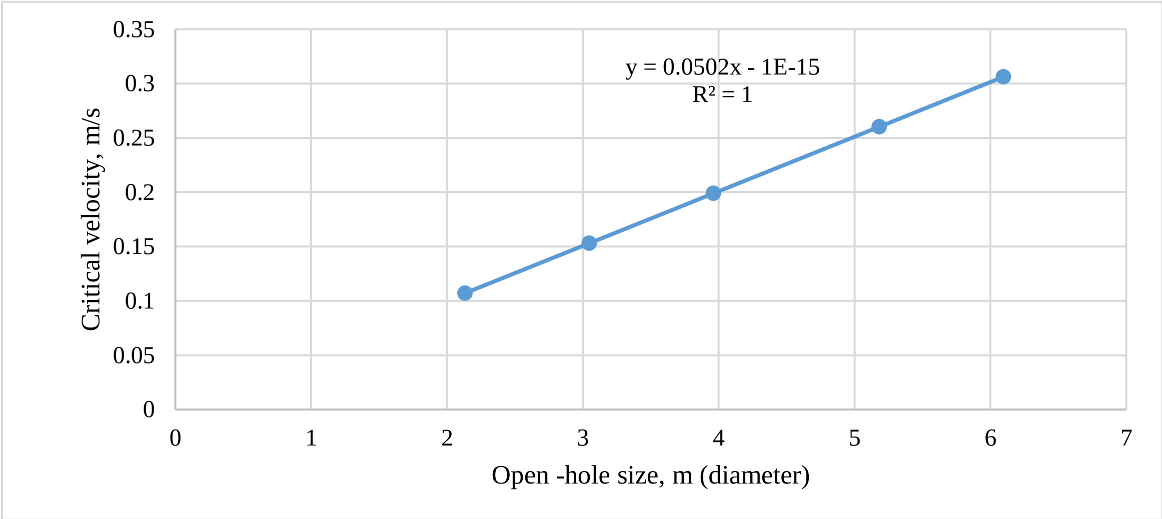

Fig. 1(B) Modeling the variation of the critical velocity of the cement slurry at 27ºC with wellbore diameter

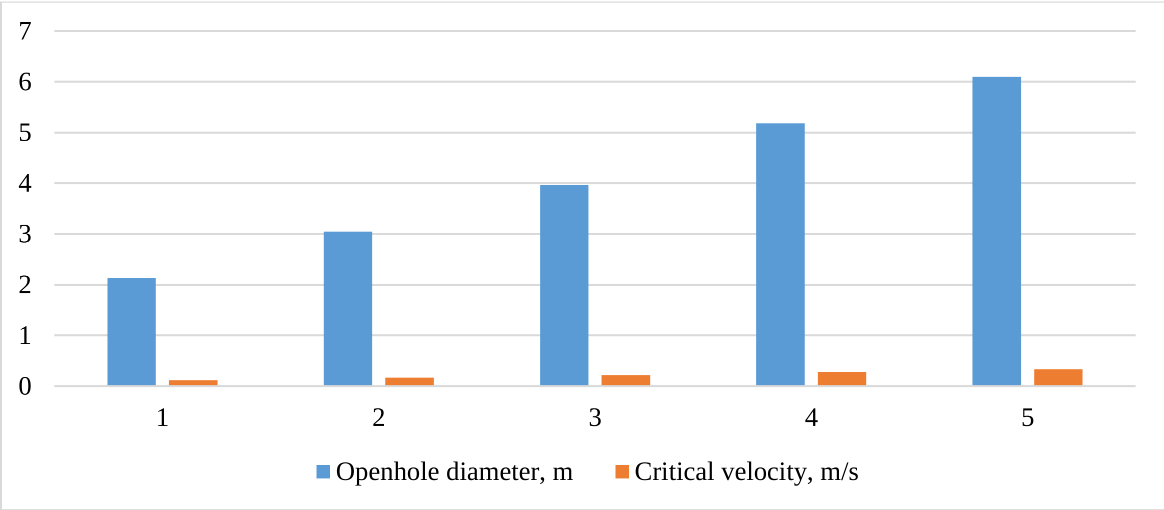

Fig. 2(A) Variation of the critical velocity of the cement slurry at 38ºC with wellbore diameter

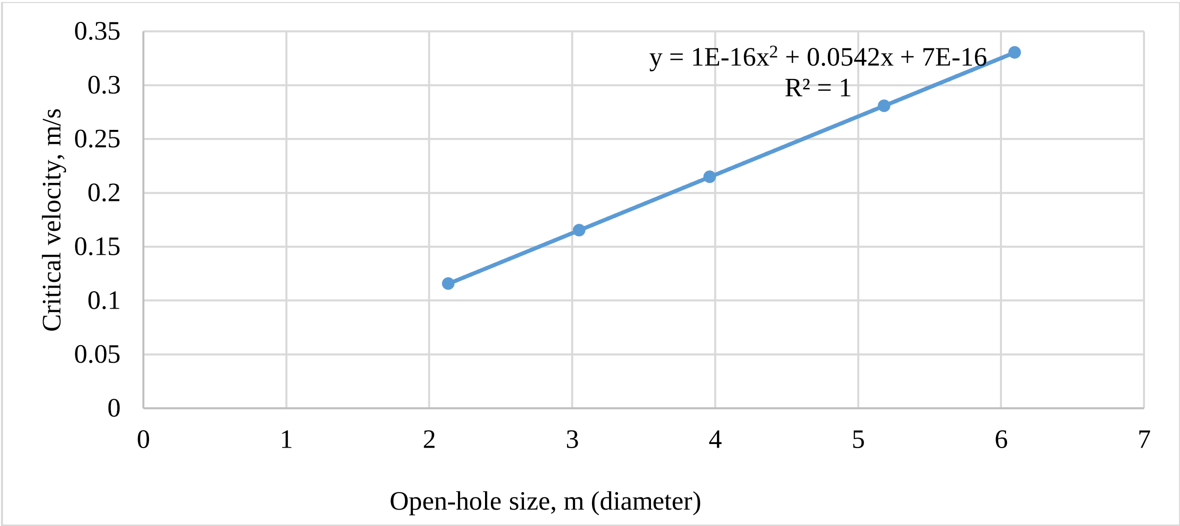

Fig. 2(B) Modeling the variation of the critical velocity of the cement slurry at 38ºC with wellbore diameter

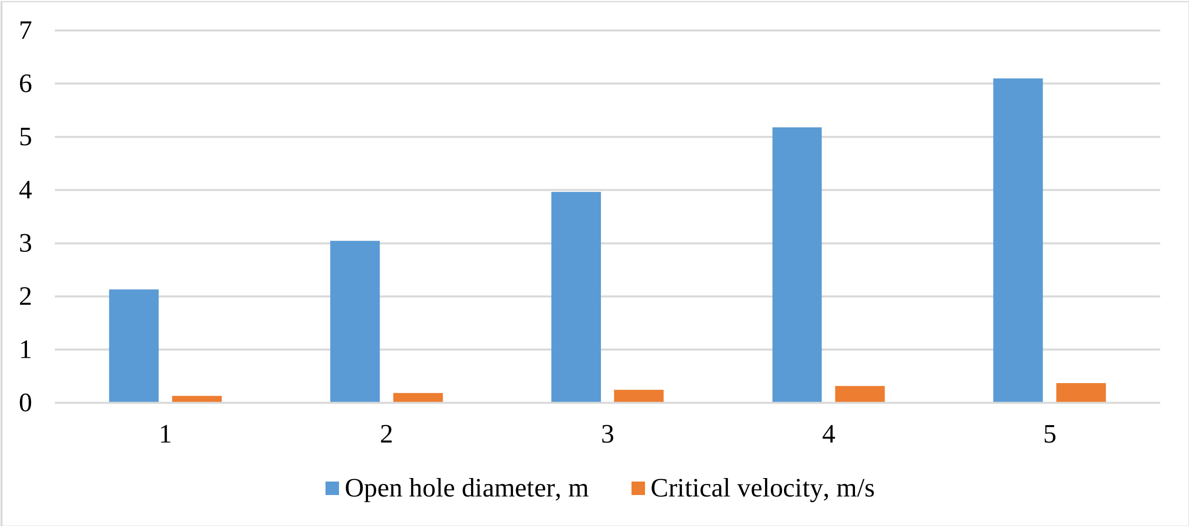

Fig. 3(A) Variation of the critical velocity of the cement slurry at 49ºC with wellbore diameter.

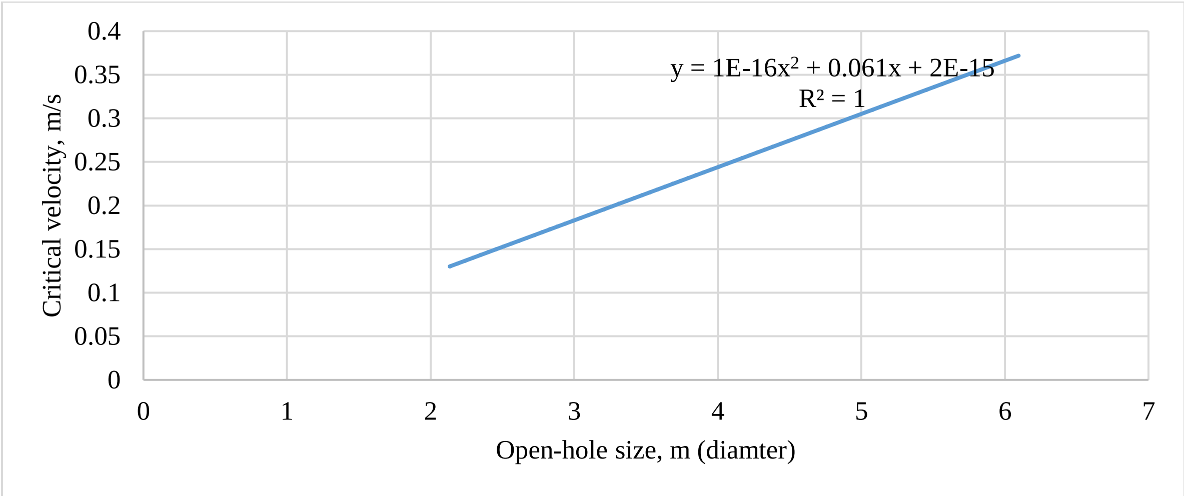

Fig. 3(B) Modeling the variation of the critical velocity of the cement slurry at 49ºC with wellbore diameter

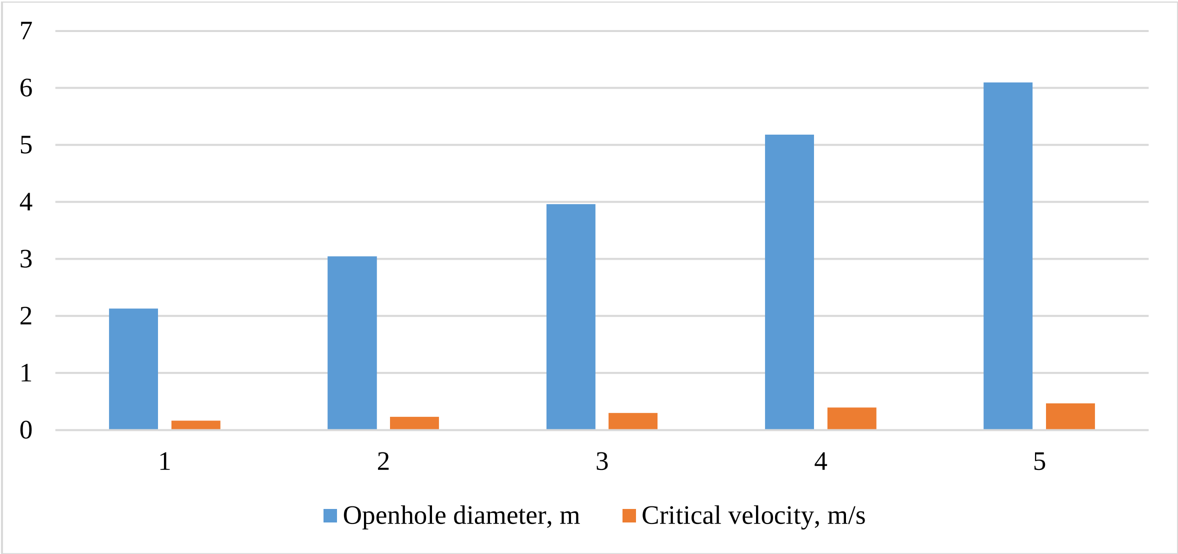

Fig. 4(A) Variation of the critical velocity of the cement slurry at 60ºC with wellbore diameter

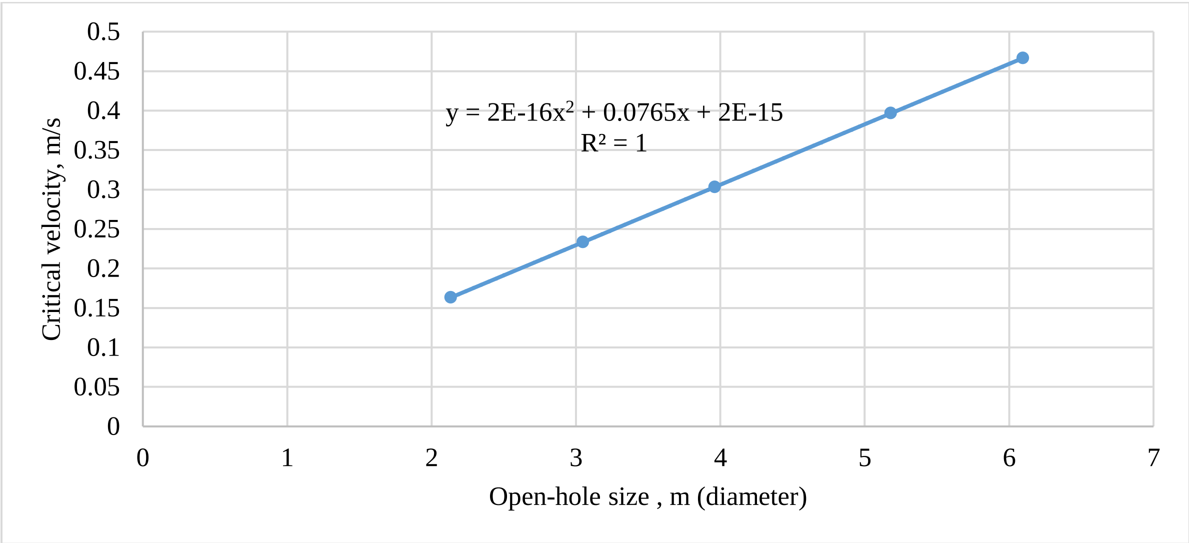

Fig. 4(B) Modeling the variation of the critical velocity of the cement slurry at 60ºC with wellbore diameter

The variation and modeling of the critical velocity of the cement slurry at 60ºC with open-hole size (wellbore diameter) are presented in Figures 4A and 4B.

It is evident from the bar chart (Figure 4A) and the graph (Figure 4B) that the critical velocity of the cement slurry increases with wellbore (open-hole) size and vice versa. The equation on the graph (Figure 4B) is the mathematical model for predicting the critical velocity with open-hole size at the test temperature of 60ºC.

The variation and modeling of the critical velocity of the cement slurry at 71ºC with open-hole (wellbore) size are presented in Figure 5A and Figure 5B. The bar chart (Figure 5A) and the graph (Figure 5B) depict that the critical velocity of the cement slurry increases with open-hole size and vice versa. The equation on the graph (Figure 5B) is the mathematical model for predicting the critical velocity with open-hole size at the test temperature of 71ºC.

It is evident from the aforesaid that the critical velocity of the cement slurry increased with open-hole size. This implies that as open-hole size increases, a higher displacement rate is required to put the cement slurry in turbulent flow or its design placement flow regime. In other words, an increase in the diameter of any section of the open hole due to wash-outs or borehole instability can cause the flow of the cement slurry to change from turbulent flow to laminar flow. The same applies to the spacer fluid, which usually has a lower density than the cement slurry. The change from turbulent flow to laminar flow can cause poor mud removal, resulting in poor cement bonding.

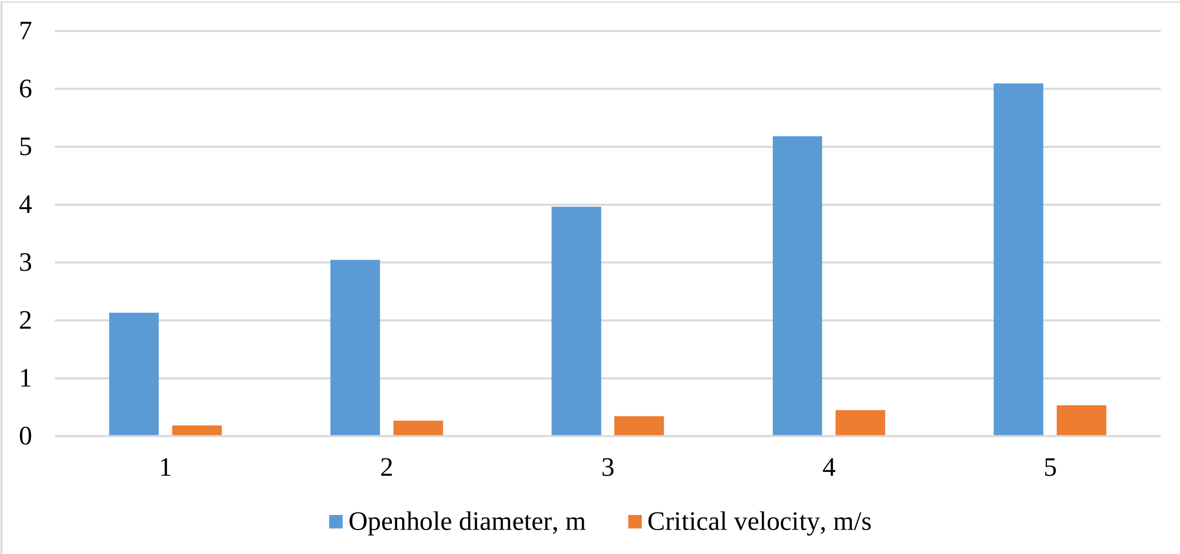

Fig. 5(A) Variation of the critical velocity of the cement slurry at 71ºC with wellbore diameter

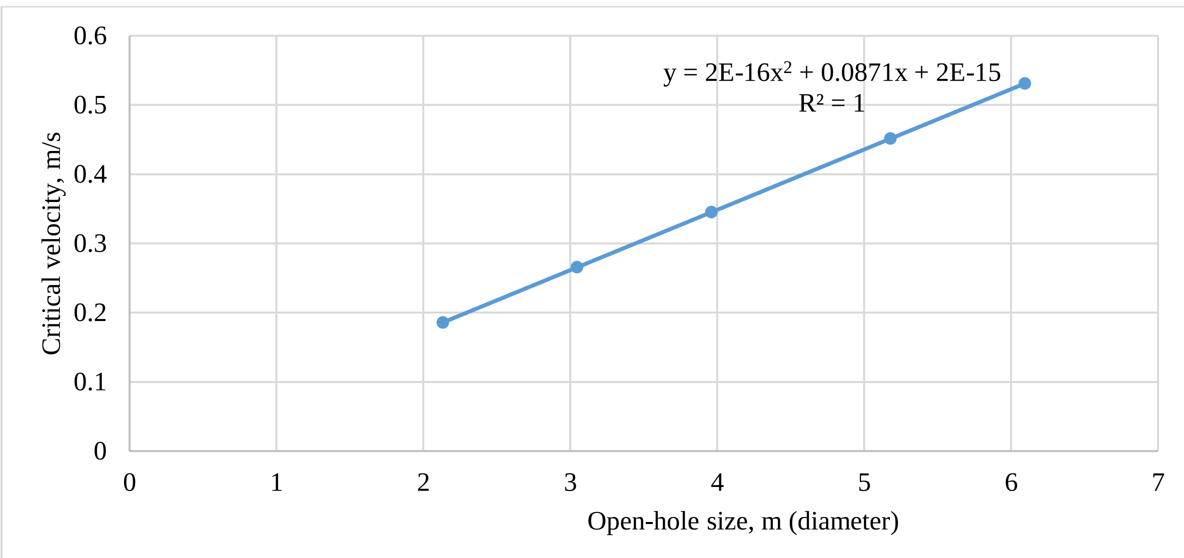

Fig. 5(B) Modeling the variation of the critical velocity of the cement slurry at 71ºC with wellbore diameter

Therefore, prior knowledge of the change in the critical velocity with open-hole size at the design stage will prompt the cementing design engineer to apply a displacement rate that will ensure that the cement slurry and the pre-flushes, especially the spacer, remain in their design flow regimes throughout the primary cementing job to ensure proper mud removal and good cement bonding to the formation and the casing. Jung and Frigaard (2022) stated that primary cementing provides structural support and stability for oil and gas wells alongside preventing leakage of hydrocarbon.

The mathematical models and the very high correlation coefficients (R^2) obtained from modeling the variation of the critical velocity of the cement slurry with open-hole size are depicted on the graphs in Figures 1 to 5. The very high correlation coefficients (R^2) show that the mathematical models can be used with a very high degree of certainty to predict the critical velocity of the cement slurry with a change in open-hole size. Therefore, when the mathematical models are generated at the design stage, the engineer can make accurate predictions of the critical velocity of the cement slurry with open-hole size, especially in emergency situations when the computer aided design and evaluation software is malfunctioning or not available.

4. Conclusion

The critical velocity of cement slurry changes with open-hole (wellbore) size. It increases with an increase in the size of the open hole and decreases with a reduction in the size of the open hole. Mathematical models can be used to predict the change in the critical velocity of cement slurry with open-hole size at a very high degree of certainty.

The application of mathematical models in predicting the change in critical velocity of cement slurry with open-hole size can be applied to save time and improve cementing job design and execution in the oil and gas industry.

Funding Statement

This research work was funded personally. No funding was received from anybody or any organization.

References

[1] Angelo Araujo Soares et al., “Cement Slurry Contamination with Oil-Based Drilling Fluids,” *Journal of Petroleum Science and Engineering*, vol. 158, pp. 433-440, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[2] American Petroleum Institute, Recommended Practice 10B-2, Recommended Practice for Testing Well Cements, 1997. [Publisher Link]

[3] Hanieh K. Foroushan et al., “Cement Placement: An Overview of Fluid Displacement Techniques and Modelling,” *Energies*, vol. 14, no. 3, pp. 1-33, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[4] Heeseok Jung, and Ian A. Frigaard, “Evaluation of Common Cementing Practices Affecting Primary Cementing Quality,” *Journal of Petroleum Science and Engineering*, vol. 208, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[5] William E. Odiete, and Elijah T. Iyagba, “Modelling the Flow Behavior of Cement Slurry with Temperature,” *International Journal of Current Science*, vol. 5, no. 4, pp. 70-73, 2015. [Google Scholar] [Publisher Link]

[6] Pegasus Vertex Inc., Drilling Industry Glossary – Critical Velocity. [Online]. Available: https://www.pvisoftware.com/drilling-glossary/critical-velocity.html/

[7] Petrowiki, PEH: Cementing, 2024. [Online]. Available: https://petrowiki.spe.org/PEH:Cementing

[8] Petrowiki, Remedial Cementing, 2021. [Online]. Available: https://petrowiki.spe.org/Remedial_cementing

[9] A. Renteria et al., “Effects of Wellbore Irregularity on Primary Cementing of Horizontal Wells, Part 1: Large Scale Effects,” *Journal of Petroleum Science and Engineering*, vol. 208, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[10] Trenchlesspedia, Critical Velocity, 2023. [Online]. Available: https://trenchlesspedia.com/definition/3820/critical-velocity

[11] Gaurang Shah, Critical Velocity, Vedantu, 2024. [Online]. Available: https://www.vedantu.com/physics/critical-velocity

[12] Mou Yang et al., “Estimating and Optimizing Wellbore Pressure During Primary Cementing in Low Pressure and Leakage Formations,” *Journal of Petroleum Sciences and Engineering*, vol. 208, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[13] Jingpeng Wang et al., “Research on Key Technologies to Improve Cementing Displacement Efficiency,” *ACS Omega*, vol. 7, no. 42, pp. 37039-37049, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[14] Zaoyuan Li et al., “Contamination of Cement Slurries with Oil Based Mud and its Components in Cementing Operations,” *Journal of Natural Gas Science and Engineering*, vol. 29, pp. 160-168, 2016. [CrossRef] [Google Scholar] [Publisher Link]