LOGIC
Journal of Engineering Design and Technology
Vol. 25 No.1 March 2025; p. 27-34

p-ISSN : 1412-114X
e-ISSN : 2580-5649
http://ojs2.pnb.ac.id/index.php/LOGIC

ANALYSIS OF LEAKAGE TEST RESULTS ON FLANGE-GASKET PIPING SYSTEM SIMULATOR DEVICE

Muhammad Naufal Abiyyi Hutagalung[1)], Syamsul Hadi [1*)], Bayu Pranoto[1)], Firman Dwiyanto[1)], Dadang Kurniawan[1)]

1) Mechanical Engineering Department, State Polytechnic of Malang, Jl. Soekarno-Hatta 9, Malang 65141, Indonesia

Correponding email: syamsul.hadi@polinema.ac.id

Abstract. Fluid leaks in piping installations often occur in the industrial sector which is detrimental due to the selection of gasket materials, flanges, and improper tightening torque of flange bolts. The fluids that are flowed can be clean water, palm oil with a fatty acid content at an acidity level (pH) of around 4, oil, solutions with a certain pH or fuel. The purpose of the simulator device analysis is to obtain data on the level of tightening torque of bolts-nuts on 1 inch pipe flanges-gaskets and the volume of leakage. The analysis method includes setting the working pressure of the fluid on the globe valve at 1 Bar, 1.3 Bar, and 1.5 Bar on the flange-gasket piping system simulator device, measuring the lowest tightening torque at which the fluid starts to leak to the highest at a condition where there is no leak at all, and two-way Anova analysis on the distribution data. The results of the study showed that the lowest bolt-nut tightening torque at 2 Nm for three M8 bolts-nuts as flange-gasket pair locks resulted in an average fluid droplet leakage of 120 ml/hour and at a torque of 4 Nm the leakage level was about a quarter of that, namely 36 ml/hour and finally at a torque of 5 Nm there was no leakage at all. Implications in industries that use fluid flow with sufficient tightening torque of nuts-bolts on flanges-gaskets can reduce-stop losses due to leakage that occurs in their piping systems.

Keywords: Fluid leaks, centrifugal pumps, fluid pressure, and bolt-nut tightening torque.

1. INTRODUCTION

Hydrolysis in the industrial process of crude palm oil into fatty acids and glycerol is carried out at a temperature of 250 ˚C and a pressure of 50 Bar for 2 hours to achieve conversion results between 96% and 99% [1]. Innovation in the simulator device in the form of a piping network device assembled on a wheeled frame table consisting of a reservoir, pipeline, circulation pump, manometer, flowmeter, glove valve to regulate working pressure, valves, fluid filler funnel, a pair of flanges, gaskets, 3 pairs of bolts and nuts equipped with torque wrenches, measuring cups and stopwatches. The purpose of the leak test analysis is to obtain data on the level of tightening torque of bolts and nuts on the 1-inch pipe flange-gasket in the piping system and data on the volume of leakage at the lowest and highest levels of tightening torque of bolts and nuts on the flange-gasket.

A piping system is a combination of interconnected pipes and is used to convey fluids, both liquid and gas, from one piping system to another piping system. Several important components in the distribution of a fluid flow from the results of a process in a piping system so that a fluid distribution process can operate include components used including pumps, manometers, flowmeters, various valves, branch connections, bend connections, and cross-section changes [2]. The operation of fluids can involve components including pumps, manometers, flowmeters, flanges and gaskets, various valves so that the flow can be monitored and controlled, including anticipating leaks.

Pumps are often found in large, medium and small-scale industries. Pumps are generally classified into 2 parts, namely positive displacement pumps and non-positive displacement pumps [3]. Centrifugal pumps are a type of pump where potential energy is converted into speed energy which comes from changing static energy into dynamic energy [4]. The liquid inside rotates due to the push of the blades, giving rise to centrifugal force which causes the liquid to flow from the center of the impeller out through the channel between the blades and leaves the impeller at high speed [5]. Generally in piping systems, pumps are used as a distribution medium to various destinations.

When the system is running, the gasket experiences stress-strain from changes in fluid flow pressure in the system, which over a long period of time will change the mechanical properties of the gasket. There are many factors that need to be considered to avoid leaks at the flange connections in the piping system. There are several factors or parameters that can cause leaks in connections including tightening torque, fluid working pressure, gasket material, gasket thickness, and flange geometry [6]. Apart from this, the number of bolt holes and bolt size as well as the flatness and smoothness of the contact between the flange-gasket influence whether or not leaks occur easily.

Flange performance is seen in the strength of the connection and evaluation of the connection needs to be carried out in a system [7]. The flanges used use stainless steel because this material is corrosion resistant and heat resistant. Stainless steel is the name given to a family of corrosion-resistant and heat-resistant steels containing a minimum of 10.5% chromium [8]. According to Smith [8], Stainless steel is used for its corrosion resistance properties or for temperatures below zero Celsius containing a minimum of 12% chromium alloy elements. This means that stainless steel flanges are resistant to corrosion with chromium levels that are higher than nickel levels, making stainless steel suitable for use in environments containing low pH or corrosive acids, and are also capable of operating at relatively high temperatures compared to brass flanges. composite, plastic, or cast iron.

Fluid leaks are very detrimental because they can reduce production efficiency in industry and are very dangerous if the fluid distributed is in the form of chemicals or gases that are categorized as dangerous or flammable if they leak into the atmosphere, especially when applied to gaskets. Leakage in gaskets depends on the torque provided by connecting or tightening the bolts and nuts which is carried out with greater gasket or tightening tension to prevent leaks [9], but this is not the case in field applications, because most tighten the bolts and nuts with a torque that is larger than normal to stop leaks, this can result in gaskets being destroyed, flange pairs not being on the same axis or bolts being damaged [10]. Fluid leaks can be detrimental and dangerous when flammable or corrosive fluids are flowed and the application of excessive torque can damage the construction. Therefore, a piping system can be simplified by means of a simulation in the form of a leak test device on a sealing clamp flange on a laboratory scale which is approached with variable values of fluid working pressure and bolt-nut tightening torque on the flange-gasket which is presented in the relationship between fluid pressure and tightening torque. on the bolt-nut on the flange-gasket.

The tightness and strength of flange connections is influenced by several factors including: gasket design and force on the bolt-nut, creep during bolt relaxation, cracks in the flange, axial force of the flange connection on rotation and deformation of the flange connection components, and uniformity of bolt tightening [11]. Several factors have been observed to influence the relationship between flange connection tightness and leakage.

Finite element analysis has been used for detailed leakage evolution [5], modeling and calculation of asymmetric nonlinear multi-bolt connections treated as a system [12], analysis of the strength and sealing performance of pipe joints [13], studying the strength of the flange-bolts mounted on gaskets. pipe joints under different bolting strategies in industry and under a combination of internal pressure and axial loading [14], evaluation of two different flange sizes of ANSI B16.5 900 pressure class [15], studying leakage evolution in detail [16], analysis of rules and regulations related to bolted flange connections on gaskets refers to ASME VIII DIV 1 requirements [17], and the leakage pressure model is in good agreement with the numerical prediction and also with experimental results [18]. The approach to proving the leakage phenomenon has been demonstrated with numerical analysis results.

2. METHODS

The research used in experimental form to obtain the relationship between fluid working pressure and bolt-nut tightening torque on flange-gaskets against fluid leakage is shown in the flow diagram in Figure 1. The simulator device is made according to the design and assembled carefully on a wheeled table, filled with fluid into the reservoir, the pump is operated, the working pressure of the circulating fluid is set, then the tightening torque on the bolts and nuts is set with a torque wrench and the fluid leaks are collected, the working pressure data of the fluid and the fluid leaks are recorded, an analysis is carried out to obtain the tightening torque limit for the nuts in conditions of fluid leaking and fluid without any leaks at all.

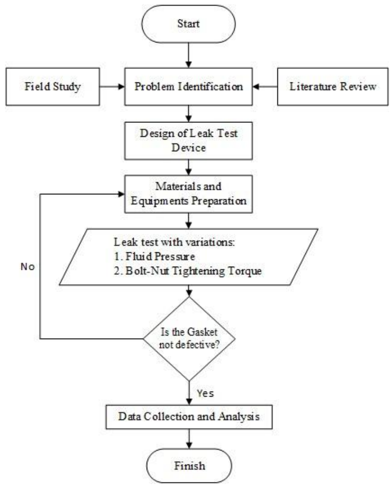

Figure 1. Flow diagram of research on the relationship between fluid pressure and bolt-nut tightening torque on flanges-gaskets against fluid leaks

Research was conducted from January to April 2024 at the Reverse Engineering Laboratory, 3rd Floor, Mechanical Engineering Building, Malang State Polytechnic, Jl. Soekarno-Hatta No. 9, Malang City, East Java. The leak test device has received a Granted Certificate from the Ministry of Law and Human Rights of the Republic of Indonesia with Number IDS000007730 entitled FLUID LEAK TEST DEVICE ON FLANGE-GASKET CLAMPING with Simple Patent protection valid until 05 October 2033 is shown in Figure 2.

Figure 2. Leak Test Device: (a) Top Left View and (b) Top Front View

Before testing, preparations are made to check whether there are leaks, including at bend connections, branch connections, pipe connections to flanges or vice versa, pipe connections to pumps, pipe connections to manometers, pipe connections to flowmeters, and pipe connections to valves. After ensuring that there are no leaks in the piping system connections, testing and data on leak levels can then be carried out. Leak detection is shown in Figure 3.

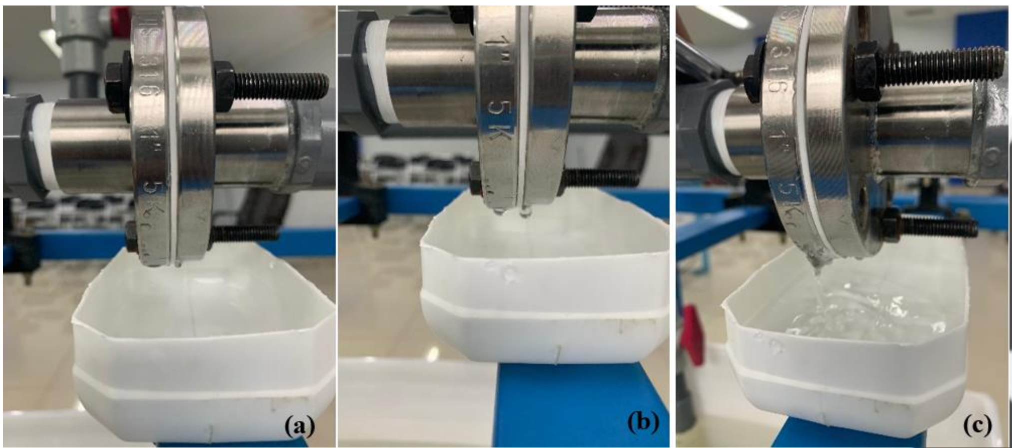

Figure 3. Levels of fluid leakage: (a) seeping, (b) dripping and (c) dripping heavily

A leak test device that has been created to determine the phenomenon of leaks that often occur in piping systems, especially in flange connections and gaskets. The fluid leak in the research carried out occurred at the flange-gasket connection where the fluid leak was collected using a container under the rectangular flange and the resulting fluid leak was transferred and poured into a measuring cup as a measuring tool to determine how much fluid had leaked from the system. The variables used in the research are fluid pressure and bolt-nut tightening torque on the flange which is shown in Figure 4. In the experiment carried out using two flanges with a hole diameter of 34.5 mm, an outer diameter of 95 mm, made of 316L stainless steel, and gaskets of the same size. with a flange, namely a hole diameter of 34.5 mm, an outer diameter of 95 mm made from PTFE (Polytetrafluoroethylene). In the two flange plates that clamp a gasket on the three plates, three bolt holes with a diameter of 10 mm are made at an angle of 120° to each other with a radius of 37.5 mm.

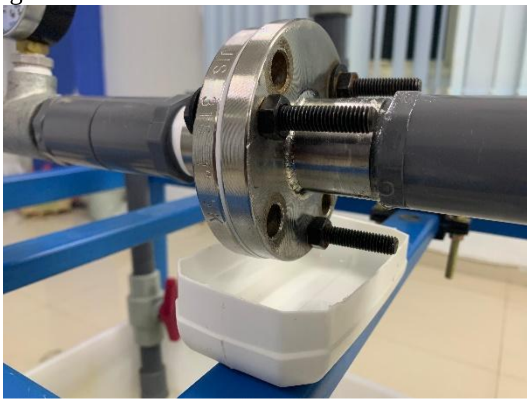

Figure 4. Flanges, gaskets and containers for collecting leaks before pouring them into a measuring cup

In connection with the limited torque wrench available in the trade of at least 5 Nm, it was created by measuring the torque using homemade equipment with a welded lever with a connector on the wrench socket with a weight of sand that had been added according to the load that should be given for sizes smaller than the 5 Nm torque is shown in Figure 5.

Figure 5. Creation of torque measurements smaller than 5 Nm which are not available in the trade

3. RESULTS AND DISCUSSION

If a fluid leak occurs, if the working pressure is low, it only takes the form of seepage, droplets and continues into a flow without becoming a spray in the radial direction of the gasket if the fluid pressure increases, so there is no need for special equipment to contain it in all radial directions of the flange, but rather it is enough to contain it in a suitable container just below it. The results of fluid leakage collected using a measuring cup are shown in Figure 6.

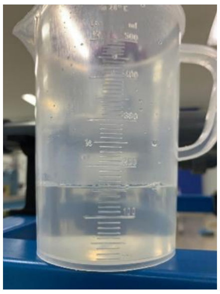

Figure 6. Leak results measured with a measuring cup

Leak test equipment experiments were carried out on flange connections where the fluid pressure was varied by 1 Bar, 1.3 Bar and 1.5 Bar, and the bolt-nut tightening torque was varied by 2 Nm, 3 Nm and 4 Nm with a test duration of 1 hour. The leak data obtained is shown in Table 1. The leakage level test was carried out with 3 replications at a working pressure of 1 Bar with a bolt-nut tightening torque of 2 Nm, 3 Nm, and 4 Nm. Likewise, at a pressure that was increased to 1.3 Bar and 1.5 Bar at a bolt-nut tightening torque of 2 Nm, 3 Nm, and 4 Nm, so that the values in Table 1 were obtained with an average of all at a bolt-nut tightening torque of 2 Nm, a value of 120 ml/hour was obtained and at a bolt-nut tightening torque of 4 Nm, a value of 36 ml/hour was obtained. The data in Table 1 can be processed and displayed into Figure 7 with the relationship between the average leakage and the bolt-nut tightening torque.

Table 1. Clean water Leak Rates

Fluid pressure (Bar)	Bolt-Nut Tightening Torque (Nm)			The average of the mean values (ml)
	2	3	4	
	Average Leakage (ml/hour)			
	95	70	10	
1	135	110	20	77.78
	125	100	35	
Average	118.33	93.33	21.67	
	90	45	60	
1.3	105	70	20	66.67
	80	75	55	
Average	91.67	63.33	45.00	
	160	110	25	
1.5	155	60	40	90.00
	135	70	55	
Average	150.00	80.00	40.00	
Grand Average	120		36	

The data in Table 1 can be displayed graphically as shown in Figure 7.

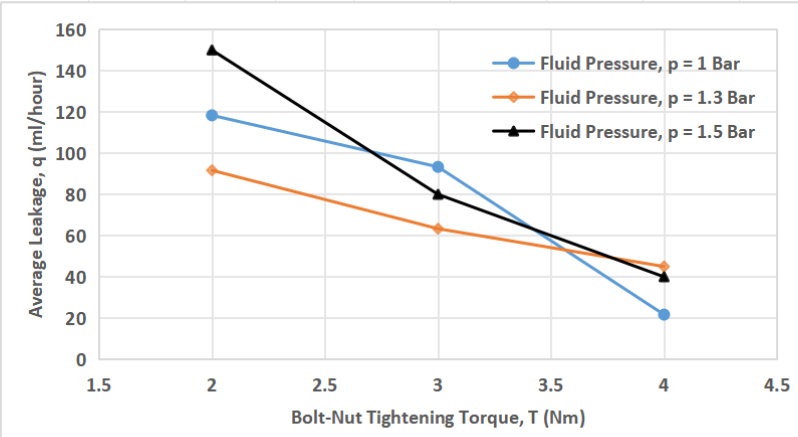

Figure 7. Fluid leak rate due to variations in fluid pressure and bolt-nut tightening torque

The fluid leakage rate decreases with increasing bolt-nut tightening torque on the flange, but it was found that for the bolt-nut tightening torque at 2 Nm, the lowest leakage rate occurred at a pressure of 1.3 Bar, which is possible because the stiffness factor of the new gasket has not provided good contact adjustment at the beginning, possibly the number of bolts is only 3 pieces, the thickness of the gasket and the number of gaskets, still do not provide perfect contact flatness, so the pattern is not consistent. At a bolt-nut tightening torque of 3 Nm, the leakage pattern at a fluid pressure of 1.5 Bar is between the working fluid pressure between 1 Bar and 1.3 Bar which shows an inconsistent pattern, and at a bolt-nut tightening torque of 4 Nm, the leakage pattern is also not consistent, but from the three differences in the increasing bolt-nut tightening torque shows that the distance of the difference is getting closer which finally at a bolt-nut tightening torque of 5 Nm, there is no more leakage. The occurrence of fluctuations and non-linearity in the leakage level can be suggested by increasing the number of bolts, increasing the thickness of the gasket, increasing the number of gaskets, and selecting a less rigid gasket material, so that it is more capable of adjusting to the clamping conditions of a pair of flanges towards perfect contact.

The capability of the leak test simulation device is limited to a reservoir capacity of 50 liters of fluid that can be circulated, a maximum pump working pressure of 1.5 Bar, and a 1-inch diameter installation pipe made of PVC material that can be used for water fluids, water with an acidity level (pH) of 4, coconut/palm oil, and a working temperature of around 50ºC.

The potential long-term effects of over-tightening can cause material deformation or faster gasket wear, the torque should be given at a sufficient level and periodically due to vibrations, and the influence of the working fluid temperature-environment requires monitoring and increased torque to provide increased service life under conditions where there are no leaks.

Data processing of leak results carried out using two-way ANOVA analysis is shown in Table 2. The independent variables in the experiment are the working fluid pressure in Bar units and the bolt-nut tightening torque in Nm units, and the dependent variable is the fluid leakage rate in ml units. The controlled variables are the constant pump motor rotation speed at 1400 rpm, the fluid is clean water, and the temperature of the test room is constant at 30 °C. If the results of the F-value for the working fluid pressure show a value greater than F-table at an error level of 5% is greater, it means that the fluid pressure hypothesis (H_{01}) is rejected and the logical consequence is that the alternative hypothesis (H_{11}) is accepted which shows that fluid pressure affects the fluid leakage value. With the same analogy, if the result of F-value for bolt-nut tightening torque (H_{02}) shows a value greater than F-table, then the hypothesis of bolt-nut tightening torque (H_{02}) is rejected and the logical consequence is that the alternative hypothesis (H_{12}) is accepted which can be interpreted that the bolt-nut tightening torque affects the fluid leakage value and also if the result of F-value for the interaction between fluid pressure and bolt-nut tightening torque shows a value greater than F-table, then the hypothesis of interaction between fluid pressure and bolt-nut tightening torque (H_{03}) is rejected and the logical consequence is that the alternative hypothesis (H_{13}) is accepted which can be interpreted that the interaction between fluid pressure and bolt-nut tightening torque affects the fluid leakage value.

Table 2. Results of two ways Annova leak test analysis

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fluid Pressure (Bar)	2	2452	1225.9	3.66	0.046
Bolt-Nut Tightening Torque (Nm)	2	32096	16048.1	47.88	0.000
Interaction between Fluid Pressure and Bolt-Nut Tightening Torque	4	4926	1231.5	3.67	0.023
Error	18	6033	335.2		
Total	26	45507			

The hypothesis from the results of fluid leak tests in piping system devices is as follows:

Null Hypothesis:

H_{01}: There is no influence of fluid pressure on the level of fluid leakage;

H_{02}: There is no influence of bolt-nut tightening torque on the level of fluid leakage; and

H_{03}: There is no interaction between influence of fluid pressure and bolt-nut tightening torque on the level of fluid leakage.

Alternative Hypothesis:

H_{11}: There is an influence of fluid pressure on the level of fluid leakage;

H_{12}: There is an influence of bolt-nut tightening torque on the level of fluid leakage; and

H_{13}: There is an interaction between influence of fluid pressure and bolt-nut tightening torque on the level of fluid leakage.

The error value in data analysis was chosen at 5% or 0.05. The analysis compared between the results of the Minitab 19 device, manual calculations, and two ways ANOVA using F-table is shown in Table 3.

Table 3. Comparison between F-value and F-table for Leak Test Variables

Independent Variable	F-value from Minitab	F-value from Manual	F-table	Consideration	Decision
Fluid Pressure	3.66	3.66	3.55	F-value > F-table	H_{01} rejected (H_{11} accepted)
Bolt-Nut Tightening Torque	47.88	47.88	3.55	F-value > F-table	H_{02} rejected (H_{12} accepted)
Interaction between Fluid Pressure and	3.67	3.67	2.93	F-value > F-table	H_{03} rejected (H_{13} accepted)

Independent Variable	F-value from Minitab	F-value from Manual	F-table	Consideration	Decision
Bolt-Nut Tightening Torque					

From Table 3, a comparison between F-value and F-table is obtained, all three of which show that F-value is greater than F-table, so the Null hypotheses (H01, H02, and H03) are all rejected, and as a logical consequence alternative hypotheses (H11, H12, and H13) are all accepted which shows that the independent variable, fluid pressure, has a significant influence on fluid leakage; the independent variable bolt-nut tightening torque has a significant influence on fluid leakage; and the independent variable interaction between fluid pressure and bolt-nut tightening torque also has a significant influence on fluid leakage.

4. CONCLUSION

Conclusions from research on fluid leakage levels in flange-gasket connections include:

1) Fluid pressure has a significant influence on fluid leakage, if the higher the fluid pressure, the higher the fluid leakage as indicated by the average value of fluid leakage at a pressure of 1 Bar, a leak of 77.78 ml/hour, at a pressure of 1.3 Bar a leak of 66.67 ml/hour, and at a pressure of 1.5 Bar there was a leak of 90 ml/hour, with the lowest leakage value at a pressure of 1.3 Bar;
2) The bolt-nut tightening torque has a significant effect on fluid leakage. The higher the tightening torque given, the fluid leakage can be overcome, but if the torque is too small than the limit value, the greater the fluid leakage value, at a torque of 2 Nm, there will be a leak of 120 ml/hour, at a torque of 3 Nm there was a leak of 78.89 ml/hour, and at a torque of 4 Nm there was a leak of 28.33 ml/hour, and at a torque of 5 Nm there was no leakage anymore;
3) The interaction of the two variables shows that the smallest amount of fluid leak is at a fluid pressure of 1 Bar and a bolt tightening torque of 4 Nm with an average fluid leak of 21.67 ml/hour; and
4) Tightening the bolt-nut at the flange-gasket connection of the piping system does not need to use a large tightening torque value, because a torque of 4 Nm is almost able to overcome fluid leaks, so it is hoped that the flange-gasket can last longer because excessive compression does not occur.

5. REFERENCES

[1] I. Noor, M. Hasan, and K. Ramachandran, "Effect of operating variables on the hydrolysis rate of palm oil by lipase," *Process Biochemistry*, 39(1), pp. 13-20, 2003, doi:10.1016/s0032-9592(02)00263-7.
[2] A. A. N. H. Susila, I. N. Piarsa, and P. W. Buana, "Geographic Information System for PDAM Tirta Mangutama Pipe Network Mapping (Sistem Informasi Geografis Pemetaan Jaringan Pipa PDAM Tirta Mangutama)," *Merpati*, vol. 2, no. p2, pp. 262-270, 2014.
[3] R. B. Dwantoro, "Effect of Number of Impeller Blades on Centrifugal Pump Performance/Pengaruh Jumlah Sudu Impeler terhadap Unjuk Kerja Pompa Sentrifugal," *Thesis*, Faculty of Engineering, Pancasakti University, Tegal, pp. 11-19, 2020.
[4] D. Wahyudi, "Comparison of Head and Capacity of Single and Series Centrifugal Pumps/Perbandingan Head dan Kapasitas Pompa Sentrifugal Tunggal dan Seri," *Energy Journal*, vol. 9, no. 1, pp. 7-17, 2019.
[5] S. Hariady, "Damage Analysis of Centrifugal Pump 53-101C WTU Sungai Gerong PT Pertamina RU III Plaju/Analisa Kerusakan Pompa Sentrifugal 53-101C WTU Sungai Gerong PT Pertamina RU III Plaju," *Journal of Technology Dissemination*, vol. 2, no. 1, pp. 29-42, 2014.
[6] H. Estrada, "Analysis of Leakage in Bolted-Flanged Joints Using Contact Finite Element Analysis," *Journal of Mechanics Engineering and Automation*, no. 5, pp. 135-142, 2015, doi: 10.17265/2159-5275/2015.03.001.
[7] M. Rahmi, Suliono, D. Canra, Rachmatullah, Y. N. Rohmat, and D. Suwandi, "Analysis of Flange Valve Strength Due to the Effect of Bolt Torque in Different Pressure and Temperature Conditions Using the Finite Element Analysis Method/Analisis Kekuatan Flange Valve Akibat Pengaruh Bolt Torque pada Kondisi Pressure dan Temperature Berbeda dengan Metode Finite Element Analysis," *Journal of Manufacturing Technology and Engineering*, vol. 2, no. 1, pp. 51-60, 2020, https://doi.org/10.48182/jtrm.v2i1.22.
[8] N. Baddoo, "Strutural Stainless Steel Design," Structural Engineer, pp. 1-10, 2013.
[9] P. Smith, "Process Piping Design Handbook Volume One: The Fundamentals of Piping Design," *Elsevier's Science & Technology*, 2013.
[10] M. Abid, and D. H. Nash, "Joint Relaxation Behaviour of Gasketed Bolted Flanged Pipe Joint During Assembly," Proceedings of the 2nd WSEAS Int. Conference on Applied and Theoretical Mechanics, pp. 315-325, 2006.
[11] G. Urse, I. Durbacă, and I. C. Panait, "Some Research Results on the Tightness and Strength of Flange Joints," Journal of Engineering Sciences and Innovation, A. Mechanical Engineering, vol. 3, no. 2, pp. 107-130, 2018.

[12] R. Grzejda, "Modelling Nonlinear Multi-Bolted Systems on the Assembly State," *Procedia Engineering*, 206, pp. 1808-1812, 2017.
[13] M. Abid, D. H. Nash, S. Javed, and H. A. Wajid, "Performance of a Gasketed Joint under Bolt Up and Combined Pressure, Axial and Thermal Loading-FEA Study," International Journal of Pressure Vessels and Piping, vol. 168, pp. 166-173, 2018.
[14] N. B. Khan, M. Abid, M. Jameel, and H. A. Wajid, "Joint Strength of Gasketed Bolted Pipe Flange Joint Under Combined Internal Pressure Plus Axial Load with Different (Industrial and ASME) bolt-Up Strategy," *J Process Mechanical Engineering*, pp. 1-10, 2015.
[15] K. A. Khan, and I. Ahmed, "Combined Loading Performance Analysis of Gasketed bolted Flange Joints with Emphasis on Bolt Scattering," Journal of Mechanical Engineering and Sciences, vol. 17, no. 3, pp. 9564-9575, 2023.
[16] W. B. Patel, P. N. Patil, R. Y. Patil, and P. P. Patil, "Analysis of Leakage in Bolted-Flanged Joints with Gasket and Under Thermal Condition, a Critical Review," International Journal of Engineering and Techniques, vol. 1, no. 6, pp. 87-92, 2015.
[17] R. Walczak, J. Pawlicki, and A. Zagorski, "Tightness and Material Aspects of Bolted Connections with Gaskets of Non-Linear properties Exposed to Variable Loads," Arch. Matall. Mater., vol. 61, no. 3, pp1409-1416, 2016.
[18] L. Bertini, M. Beghini, C. Santus, and G. Mariotti, "Metal to Metal Flanges Leakage Analysis," Proceedings of the ASME 2009 Pressure Vessels and Piping Division Conference, Prague, Czech Republic, July 26-30, 2009.