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Tribological Exploration on Pigging System using Computational Simulation

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Abstract: Pipeline inspection gauge or known as PIG basically a device which is inserted into a pipeline with the purpose of cleaning or inspecting the pipeline for example in oil and gas industry. Pipeline pigging enhances the flow rate and corrosion control in the pipeline. During operation, the PIG is subjected to frictions and wear that occur between the sealing disc and the pipeline wall. The objective of this study is to simulate the contact pressure between the PIG sealing disc and the inner pipeline during pigging process. Other than that, the study is conducted to calculate the wear volume on the PIG sealing disc as the distance of pigging operation increase. The simulation is performed using COMSOL Multiphysics 5.3. The analytical calculation implemented Archard's law formula. The result showed the higher the normal load applied to the PIG sealing disc, the higher the contact pressure between the sealing disc and the pipeline. Next, when the PIG travel through a pipeline with normal load applied, the volume loss of PIG sealing disc is increasing. As a conclusion, when the PIG is travel through a pipeline during pigging, the PIG is subjected to various conditions such as friction and wears which can affect the pigging performance.

Index Terms: Tribology, Computational Simulation, Pigging, Wear, Sealing Disc.

I. INTRODUCTION

The sealing disc of pipeline inspection gauge (PIG) is sized between 3% - 10% larger than the internal diameter of the pipeline [1]. Problem arise when the oversize sealing disc are operated in the pipeline. The contact pressure on sealing disc and pipeline wall is high due to the larger size of the sealing disc causing high friction rate [2].

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The purpose of larger diameter of sealing disc than the inner diameter of the pipeline is to ensure all the debris on the wall of the pipeline are clean through effectively.

The friction is due to the sliding contact of the sealing disc and the pipeline wall, as most of the PIG weight is directed to the sealing disc [3].

Previously, Zhang et al. [4], shows that a tight seal provides the necessary condition to achieve the desired differential pressure across the PIG so as to overcome the friction force and drive it through the pipeline.

PIG is subjected to wear as the PIG is too tight to the inner pipeline. As the sealing disc wear, leakage will take place causing the differential pressure across the PIG to drop. Excessive wear can lead to the failure of the sealing disc and can potentially cause the PIG to stick within the pipeline. The aim for this research is to simulate the contact pressure between the PIG sealing disc and the inner pipeline during pigging as well as prediction the wear volume of the PIG sealing disc as the distance of pigging operation increases. To date, this study utilizes soft PIG materials in order to study behavior of pigging system in low cost applications.

II. METHODOLOGY

This study investigates the contact pressure and wear between the PIG sealing disc and the inner part of the pipeline thus to provide data for further development of the improvement of the PIG sealing disc. Wear can cause the sealing disc of the PIG cannot be used for a long period which is assess through volume loss from the used of computational simulation.

The study utilized finite element analysis using COMSOL Multiphysics software for modeling and simulation the PIG as shown in Figure 1. The characteristic of the pipeline and PIG sealing disc that are used to conduct the research are according to Zhang et al. [4, 5]. In this study, the steel plate Young's modulus, Poisson's ratio and density are 210 GPa, 0.28 and 7850 kg/m^3 respectively. The PIG sealing disc Young modulus, Poisson's ratio and density are 1.66 MPa, 0.499 and 1200 kg/m^3 respectively. The simulation was focusing to determine the contact pressure between the sealing disc and flat steel plate. The load that are used in the simulation in the range between 8 kN to 15 kN to show the effect of load to the sealing disc. The sizes of sealing disc used are in the range between 50 mm to 80 mm. The study utilizes steel plate as substitute to pipeline to simplify the simulation. The simulation also conducted without any liquid as lubrication between the PIG sealing disc and the steel plate.

After the model been analyzed, the model is proceeds to analyze the contact pressure between the sealing disc and the steel plate. The wear volume is calculated by using Archard's law formula as utilizes in previous study [6]. First, before calculating the wear volume, the wear rate is needed to be determined.

The wear rate is obtained through Zhang et al. [7]. Only symmetrical model of PIG was used to minimize due to the computer limitation.

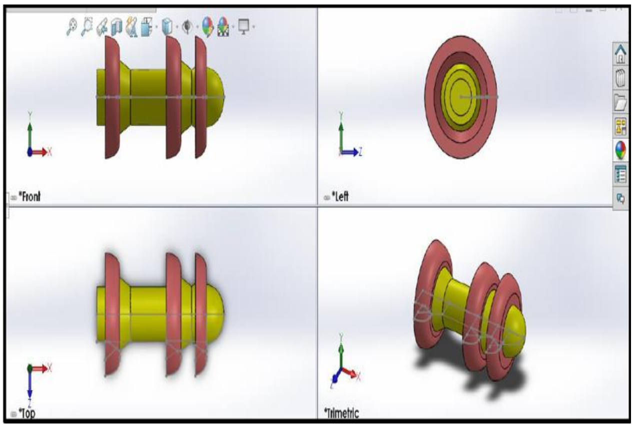


Fig. 1 Actual model of the Polyurethane PIG

III. RESULT AND DISCUSSION

The aim for this research is to simulate the contact pressure between the PIG sealing disc and the inner pipeline during pigging as well as prediction the wear volume of the PIG sealing disc as the distance of pigging operation increases.

According to graph in Figure 2, as the normal load applied to the PIG sealing disc increase, the contact pressure between the sealing disc and the steel plate is increase. The highest contact pressure recorded is 1000 MPa and the lowest is 600 MPa. Based on the graph, when larger radius of sealing disc used, the contact pressure reading is decrease. This is because larger sealing disc have more room to distribute higher normal load applied causing less contact pressure to the steel plate. For example, when 80 mm radius of sealing disc used the maximum contact pressure recorded at 850 MPa and the lowest at 600 MPa while 50 mm radius of sealing disc shows the maximum contact pressure is 1000 MPa and the lowest is 750 MPa. The average contact pressure difference between each radius of sealing disc used is 54.17 MPa.

Based on the simulation, higher normal load tends to create higher contact pressure between the PIG sealing disc and the steel plate as shown in Figure 2. When the normal load is applied, the load distributed inside the PIG sealing disc forcing the PIG sealing disc to move downward to make contact with the steel plate. The contact then yields contact pressure between the PIG sealing disc and the steel plate. During the contact of two surfaces, initially the contact will only occur at few points to support the normal load applied [8]. As the normal load is increases, the surfaces move closer together causing existing contact grow to support the increasing load. At the region of the contact spot, deformation occur establishing stress that oppose the applied load.

Frictional forces can act either good or bad. Friction causes energy loss and wear of moving surfaces in contact (Figure 4). As the sliding distance increase, the wear volume of PIG sealing disc is increase consistently as shown in Figure 3. This is because the wear rate of the PIG sealing disc is assumed consistent over the distance of PIG sliding. The highest wear volume recorded is 17.89 mm^3 and the lowest is 2.39 mm^3. Based on the graph, when higher normal load applied to the PIG sealing disc, the wear volume is also increase. This is because when higher normal load applied to the sealing disc, it creates more sliding contact towards the steel plate thus causing higher wear volume of PIG sealing disc. For example, the when 8 kN of normal load is applied to the PIG sealing disc the maximum wear volume is 9.54 mm^3 and the lowest is 2.39 mm^3 when the sliding distance is 20 m and 5 m respectively while when 15 kN of normal load is applied the maximum wear volume is 17.89 mm^3 and the lowest is 2.39 mm3 when the sliding distance is 20 m and 5m. The average wear volume difference between each normal load applied is 0.74 mm^3.

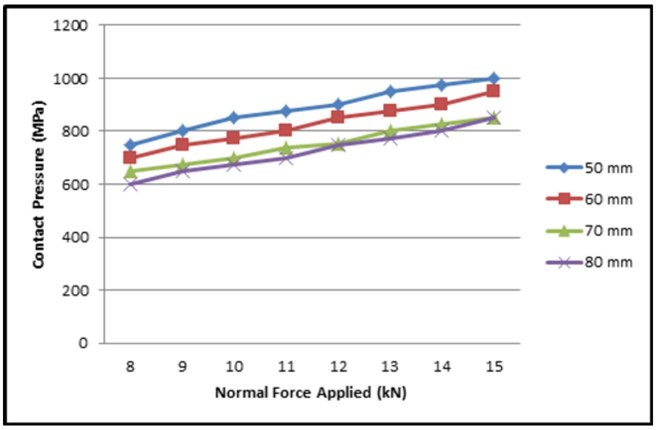


Fig. 2 Overall contact pressure reading under different normal force applied

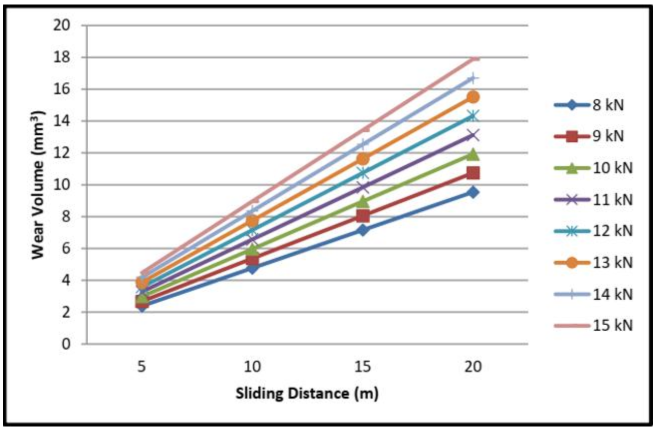
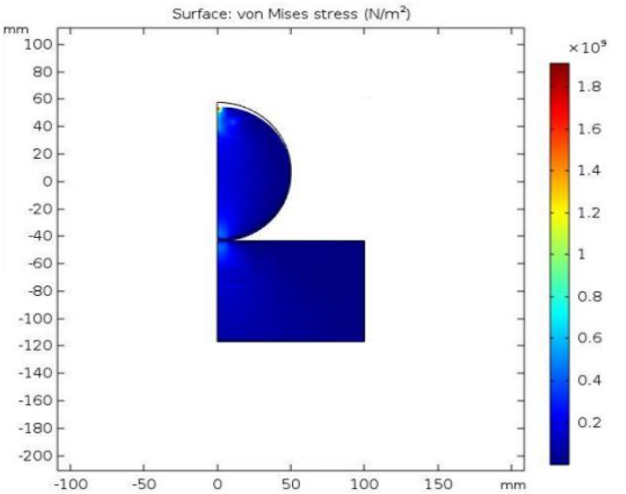


Fig. 3 Overall wear volumes with different normal load applied

As the PIG travel through the pipeline, the wear volume is increasing. The PIG sealing disc tends to create surface contact with the pipeline causing friction and wear to the sealing disc. Polymer-based materials have high viscoelasticity that are subjected to plastic deformation, high friction and wear [5].

Contact between asperities with high local stress and are repeated during sliding motion with or without lubrication causing fatigue wear. Softer material will undergo plastic deformation as result of fatigue wear [5]. The interaction of the rigid asperities of the steel surfaces during sliding causing the top layered abrasive pattern of the rubber surface will experience repeated compression, expansion and reversed shear stress under cyclic loading. During the pigging process, certain volume of PIG sealing disc from the rubbing pairs will be removed.



The result from current study show the range of wear volume is between 2.39 mm^3 to 17.89 mm^3 when the PIG travel 5 m to 20 m with 8 kN to 15 kN of normal load applied to the PIG sealing disc. The result from [5] shows the range of wear volume is between 1 mm^3 to 8.45 mm^3 when the PIG travel 100 m to 400 m with 2 N to 4 N of normal load is applied to the PIG sealing disc. The range of wear volume is between 1.27 mm^3 to 6.00 mm^3 when the PIG travel 100 m to 400 m with 2 N to 4 N of normal load is applied to the PIG sealing disc which supported by previous study [5].

All the study shares common result whereas the sliding distance increase, the wear volume of the PIG sealing disc increases. When the PIG travel through a steel place with normal force is applied, the PIG sealing disc is creating surface contact with the steel plate and in motion against with the steel plate causing friction and wear to the sealing disc.

There are differences of result between current study and previous study where the amount of wear volume of current study is relatively larger for short distance than both of previous study. This is because, the amount of normal load applied to the PIG sealing disc in current study is larger than previous study. Wear volume of PIG sealing disc tend to increases as the applied load increases during the sliding motion [5]. Surface contact was found to be directly contributed to the rate of wear, even under normal loading [1]. Compares the volume losses at all sliding distances under normal load, it can be seen that the volume losses are directly proportional to all variables. From the simulation, the contact pressure in between hydraulic spool and valve was found to be influence by the normal load. The stress distribution of contact pressure on the model under normal load as shown in Figure 4, which is believed to be caused by surface deformation of both sealing disc and pipe.

IV. CONCLUSION

The study also can be used as a reference to enhance the pigging process performance. Based on the data gain in this study, the data can be used to study on the relationship between the contact pressures and wear of PIG sealing disc as contact pressure and wear influence the effectiveness of the pigging process.

It shows that higher normal load applied towards the PIG sealing disc causing higher contact pressure. As we know that higher contact pressure between the sealing disc and the steel plate create more friction thus causing high wear volume of the PIG sealing disc which become ineffective over time. Wear volume of the PIG sealing disc is increase when the sliding distance increase with higher normal load applied. Excessive wear volume over certain distance can cause the pigging ineffective because of the differential pressure inside the pipeline decrease. The PIG is highly possible to get stuck inside the pipeline as the differential pressure decrease causing work delay and expensive cost.

The percentage of overlap between the sealing disc and pipe can be reduced by using finer meshing and different contact surface from this study. The volume losses were found to be directly influenced by the sliding distances and load. Regardless of the load value, the shortest sliding distance generated the highest loss in volume. This is supported by the stress distribution of contact pressure which is regarded to the surface deformation of both disc and pipe plate in contact.

This study is hoped to include more variables thus thorough understanding of wear mechanism can be presented through computational simulation. The modelling of the PIG sealing disc and pipe may also be improved with advancement in computational power and geometry.

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