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PEARSON CORRELATION ANALYSIS OF OIL TESTING PARAMETERS ON REMAINING USEFUL LIFE (RUL) IN GEARBOX CHAIN BUCKET ELEVATOR

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Abstract
The gearbox in a chain bucket elevator system is a critical component of the cement production process and relies heavily on the reliability of the lubrication system. As operating hours increase, lubricating oil quality degrades, potentially affecting its remaining useful life (RUL). This study aims to analyse the linear relationship between oil-test result parameters and Remaining Useful Life (RUL) for chain bucket elevator gearboxes using the Pearson correlation method. The data used are 50 laboratory test results for the gearbox oil chain bucket elevator at Cement Mill Indarung VI, PT. Semen Padang collected from June 2019 to October 2025. The oil testing parameters analysed include DV Visc 40°C, DV Visc (%), ISO >6, NAS, Contamination Index, Ferrous Index, Chemical Index, Dielectric, and % Water. Data were analysed using the Pearson correlation method and visualised as a heatmap. The analysis results showed that the viscosity parameter had the strongest negative correlation with RUL, with a value of -0.741 for DV Visc 40°C and -0.658 for DV Visc (%). The Contamination Index and % Water parameters also showed a negative correlation with RUL, albeit with a lower level of influence. In practice, the results of this study can serve as a basis for oil condition monitoring to support condition-based maintenance strategies, enabling more timely oil change decisions and minimising the potential for gearbox failure.
Keywords: Gearbox, Lubricating Oil, Remaining Useful Life, Pearson Correlation, Condition-Based Maintenance

INTRODUCTION

The gearbox in the chain bucket elevator system is a critical component that maintains continuous material flow in the cement industry (Yudistira & Fahruddin, 2024). One example of its application is PT. Semen Padang, the oldest cement manufacturing company in Indonesia, was founded on March 18, 1910, in Padang, West Sumatra (Muhammad Nur et al., 2024). In the cement production process, especially in the Cement Mill unit, chain bucket elevators are used to vertically transport large loads in continuous operation, making gearbox reliability a key factor in maintaining production stability (Lutfi & Tarigan, 2023). Gearboxes operate under high-load conditions, continuous operation, and in dusty, relatively high-temperature environments, so they rely heavily on the performance of the lubrication system to maintain reliability and service life. Lubricating oil reduces friction, suppresses wear, controls temperature, and protects the gearbox's internal components from corrosion and contamination (Agustini et al., 2024). However, as operating hours increase, oil quality will degrade due to oxidation, particle contamination, water ingress, and decreased lubricating additive performance. Changes in these parameters can be used as indicators of oil condition and its remaining useful life (RUL) (Chokelarb et al., 2024).

The development of data analysis and machine learning technology enables the processing of oil testing data more systematically and objectively (Muhammad Idris, 2025). One of the initial approaches in data analysis is correlation analysis, which aims to identify relationships between variables based on their level of correlation (Subhaktiyasa et al., 2025). Previous studies on oil condition analysis have generally focused on predictive modelling or machine learning-based approaches to estimate component service life (Jangamwadimath et al., 2022). This approach tends to emphasise prediction accuracy, while the initial understanding of the linear relationship between oil testing parameters and RUL, as a basis for interpreting oil degradation conditions, remains relatively limited (Prawiroredjo et al., 2021). Specifically, in the chain bucket elevator gearbox at PT. Semen Padang studies that utilise Pearson correlation analysis to identify linear relationships between parameters based on actual operational data have not been widely reported. Furthermore, the use of correlation analysis as an initial step to explore parameters with a dominant relationship to changes in oil RUL remains a rare primary focus of research (Prawiroredjo et al., 2021). This condition indicates the need for an analytical approach that provides a systematic initial understanding of the relationships between oil testing parameters and RUL (Mutiarani & Darwis, 2023).

Correlation analysis is a statistical method used to determine the level of linear relationship between two or more variables based on observational data (Kasliono et al., 2023). In this study, Pearson correlation analysis based on actual industrial data from 2019 to 2025 is used as the main approach to examine the relationship between oil test results and oil Remaining Useful Life (RUL) in the chain bucket elevator gearbox of Cement Mill in Indarung VI PT. Semen Padang (Leni, Dwiharzandis, et al., 2023). Through correlation analysis, the relationship can be quantified, enabling identification of which parameters are more strongly associated with changes in RUL (Subhaktiyasa et al., 2025). The resulting correlation coefficient value shows the strength and direction of the relationship between variables (Trianto Syahbannu Prayoga & Suliadi, 2024). Parameters with high RUL correlation values play a more dominant role in describing the condition and remaining service life of the oil and reflect the working conditions and level of oil degradation during the operating period. In contrast, low correlation values indicate a weak relationship (Kohan et al., 2025). Correlation heatmaps simplify the interpretation of analysis results by visually displaying relationships between parameters (Leni, 2023).

The purpose of this study is to analyse the linear relationship between oil test parameters and oil Remaining Useful Life (RUL) using Pearson correlation, and to identify parameters that have a dominant influence on changes in oil RUL in chain bucket elevator gearboxes. This approach is expected to provide a basis for data-based analysis in oil condition evaluation and support condition-based maintenance planning (Whitby, 2021).

METHOD

This study uses a quantitative data analysis approach to examine the relationship between oil testing parameters and the Remaining Useful Life (RUL) of oil in chain bucket elevator gearboxes (Subhaktiyasa et al., 2025). This study aims to identify the level and direction of the relationship between oil testing parameters and the RUL as a basis for evaluating oil condition and degradation. The analysis was carried out using RapidMiner software for data processing and visualisation, specifically using a heatmap correlation matrix.

The research method was structured in stages, starting from the literature review to the analysis and discussion of the results, as shown in the research flowchart in Figure 1.

Figure 1. Research Flowchart

This research begins with a literature review phase aimed at obtaining a relevant theoretical basis, including the concepts of lubrication and oil degradation, the function and performance of chain bucket elevator gearboxes, the concept of Remaining Useful Life (RUL), and correlation analysis methods. This literature review is used as a basis for determining the research variables and the applied analysis methods. Furthermore, research data were collected from laboratory test results on the oil from the Cement Mill chain bucket elevator gearbox at Indarung VI PT. Semen Padang sourced from the Maintenance Reliability Unit Laboratory of PT. Semen Padang. Data were collected in the period June 2019 to October 2025 with the nomenclature 6Z1J10 as many as 50 data representing the actual condition of the oil during the operating period, including the parameters DV Visc 40°C, DV Visc (%), ISO >6, NAS, Contamination Index, Ferrous Index, Chemical Index, Dielectric, and % Water, which were then used as the main material in the correlation analysis process. In addition, the RUL is determined as the difference between the maximum service life of the oil under company standards (500 working hours) and the actual operating hours, thus representing the remaining service life of the oil under test conditions.

The next stage is data preprocessing, which prepares the data for analysis by checking data completeness, adjusting formats, and normalising the scales of oil testing parameters (Maharana et al., 2022). Normalisation was performed to ensure that differences in variable value ranges did not affect the results of the correlation analysis. The data were then processed in RapidMiner, with variables selected for analysis and a data structure constructed as a basis for the correlation analysis. The data analysis stage used Pearson's correlation to examine the relationship between oil testing parameters and Remaining Useful Life (RUL). The Pearson correlation coefficient was used because the analysed data were continuous numerical and aimed to identify linear relationships between variables. The

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correlation results were visualised as a correlation heatmap to facilitate interpretation of the levels and directions of relationships between variables (Leni, Erawadi, et al., 2023). The final stage of the research is the presentation of results and discussion, which is carried out by analysing the relationship patterns in the correlation heatmap and linking them to lubrication conditions and oil degradation characteristics in the chain bucket elevator gearbox, thereby obtaining conclusions aligned with the research objectives.

RESULTS AND DISCUSSION

This research used a quantitative data analysis approach, with Pearson's correlation, to examine the relationship between oil testing parameters and the Remaining Useful Life (RUL) of oil in a chain bucket elevator gearbox. Data processing was performed using RapidMiner software.

The oil testing data that had been prepared were first processed through a normalisation stage using the Z-transformation method as a technical standardisation step to standardise the scale across variables (Permana & Salisah, 2022). Furthermore, the analysis of the relationship between variables was carried out using the Pearson correlation coefficient, as the data were numerical and aimed to measure the strength and direction of the linear relationship (Alsaqr, 2021). Even though normalisation is carried out, the Pearson correlation is independent of the data scale, so normalisation does not affect the resulting correlation coefficient.

The results of the correlation analysis between oil testing parameters and Remaining Useful Life (RUL) are displayed as a correlation matrix heatmap in Figure 2. The correlation values range from -1 to +1, where positive values indicate a unidirectional relationship, while negative values indicate an inverse relationship. The greater the absolute value of the correlation, the stronger the relationship between the variables (Kohan et al., 2025). Heatmap visualisation is used to facilitate the identification of relationship patterns between oil and RUL test parameters.

Attributes	DV Visc %	Contam Idx	Fe Idx	Chem Idx	Dielectric	% Water	DV Visc 40C	ISO >6	NAS	RUL_jam
DV Visc %	1	0.133	-0.056	-0.144	0.039	0.131	0.929	-0.307	-0.340	-0.658
Contam Idx	0.133	1	-0.052	-0.087	0.054	0.999	0.101	0.434	0.274	-0.255
Fe Idx	-0.056	-0.052	1	-0.071	0.062	-0.052	-0.043	0.154	0.182	0.005
Chem Idx	-0.144	-0.087	-0.071	1	0.830	-0.059	-0.110	-0.213	-0.060	0.107
Dielectric	0.039	0.054	0.062	0.830	1	0.076	0.038	-0.221	-0.040	0.038
% Water	0.131	0.999	-0.052	-0.059	0.076	1	0.099	0.431	0.275	-0.255
DV Visc 40C	0.929	0.101	-0.043	-0.110	0.038	0.099	1	-0.322	-0.295	-0.741
ISO >6	-0.307	0.434	0.154	-0.213	-0.221	0.431	-0.322	1	0.712	0.015
NAS	-0.340	0.274	0.182	-0.060	-0.040	0.275	-0.295	0.712	1	0.063
RUL_jam	-0.658	-0.255	0.005	0.107	0.038	-0.255	-0.741	0.015	0.063	1

Figure 2. Heatmap Correlation Matrix of Oil Testing Parameters against RUL

The analysis results show that the DV Visc 40°C parameter has the strongest negative correlation with RUL, with a value of -0.741, indicating that changes in oil viscosity at 40°C are closely related to a decrease in oil service life. The DV Visc % parameter also shows a fairly strong negative correlation with the RUL of -0.658, reinforcing the indication that changes in viscosity characteristics are the main factor in oil degradation. The strong negative correlation between viscosity parameters (DV Visc 40°C and DV Visc %) and Remaining Useful Life (RUL) can be explained theoretically by lubricant degradation during operation. Changes in oil viscosity are generally influenced by shear thinning, oxidation, and additive degradation caused by mechanical loads and high operating temperatures. These conditions reduce the oil's ability to form a stable lubricating film between the surfaces of gearbox components. A decrease in the thickness of the lubricating film increases the likelihood of direct contact between metal surfaces, thereby accelerating wear and reducing oil service life (Abdurohman, 2022). Thus, the increase in viscosity deviation is inversely proportional to the RUL value obtained from the correlation analysis results. The Contamination Index and % Water parameters each have a negative correlation with RUL of -0.255, the presence of water in the Oil acts as a contaminant, reducing the strength of the lubricant film and accelerating oxidation and additive degradation (Harahap et al., 2022). In addition, water containing solid particles can increase the potential for abrasive wear and corrosion of gearbox components (Pujono & Nur Fauzi, 2020). Although the correlation value is lower than the viscosity parameter, contamination and water content accumulation in the oil still accelerate lubricant degradation and reduce RUL during operation. Other parameters, such as Ferrous Index, Chemical Index, Dielectric, ISO >6, and NAS, show relatively low correlation with RUL, indicating they do not exert a dominant influence on the analysed data.

In addition to the relationship with RUL, the heatmap shows a very strong positive correlation among several oil-testing parameters. The Contamination Index and % Water has a near-perfect correlation of 0.999. This very high correlation indicates that the two parameters are closely related and reflect a common degradation phenomenon (Putra et al., 2021). This condition indicates potential multicollinearity: increasing water content in oil directly contributes to higher contamination levels, so that the DV Visc % and DV Visc 40°C are not completely independent, and they show a correlation of 0.929. This strong positive relationship indicates that these parameters change simultaneously and represent an interconnected oil-degradation process. However, although these parameters are positively correlated with each other, they are negatively correlated with RUL, indicating that collective changes in oil test parameters contribute to a reduction in oil service life (Bie et al., 2021). Thus, this correlation analysis provides an initial overview of the oil testing parameters most closely related to Remaining Useful Life and can serve as a basis for monitoring oil conditions in chain bucket elevator gearboxes.

Based on the correlation heatmap analysis, the parameter with the highest correlation with Remaining Useful Life (RUL) was selected for further visualisation. This visualisation aims to show the relationship between oil testing parameters and RUL clearly and to strengthen the interpretation of

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the obtained correlation results. The first parameter visualised is DV Visc 40°C because it has the strongest negative correlation value to RUL. Visualisation. The relationship between DV Visc at 40°C and RUL is shown in Figure 3. Using a scatter plot visualisation that shows a tendency for oil service life to decrease with increasing viscosity, indicating that viscosity deviations at 40°C play a significant role in the oil degradation process in the chain bucket elevator gearbox.

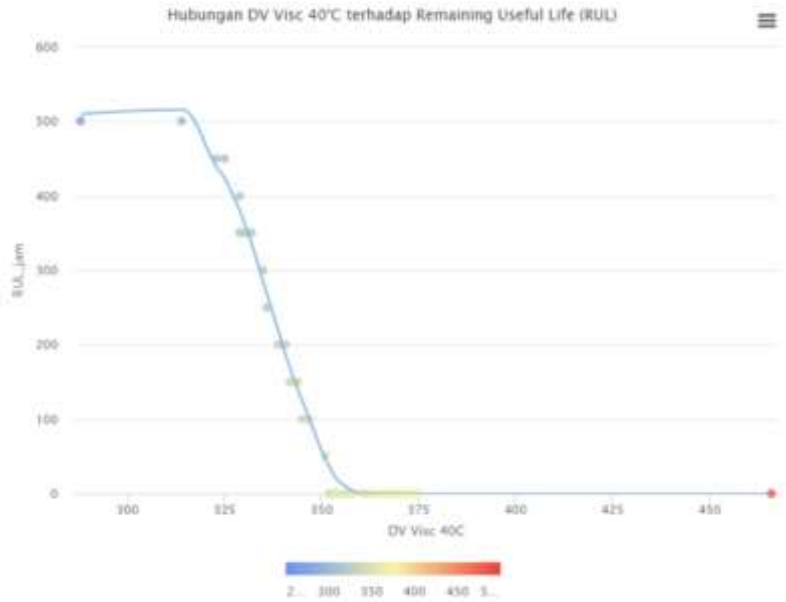

Figure 3. Visualisation of the relationship between DV Visc 40°C and RUL

Next, the visualisation continues for the DV Visc % parameter to strengthen the findings on the effect of viscosity on RUL. The relationship between DV Visc % and RUL in Figure 4 shows a similar pattern to DV Visc 40°C, where a decrease follows an increase in relative viscosity changes in Remaining Useful Life. The consistency of the relationship pattern in these two parameters indicates that oil viscosity characteristics, both absolute and relative, are the main indicators in determining oil service life.

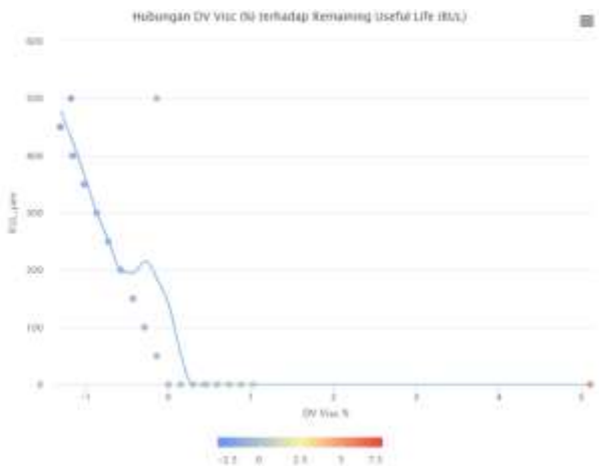

Figure 4. Visualisation of the relationship between DV Visc (%) and RUL

The data distribution in the scatter plot shows a linear trend, consistent with the Pearson correlation coefficient, indicating that RUL decreases as the oil testing parameters change.

In addition to visualising the relationship between parameters and RUL, the relationships among oil testing parameters are also visualised to clarify the oil degradation process. Visualization between Contamination Index and % Water as well as DV Visc % and DV Visc 40°C is done to show that these parameters experience changes simultaneously and represent the same degradation mechanism, although positively correlated with each other, these parameters actually have a negative correlation with RUL, which indicates that collective changes in oil testing parameters contribute to a decrease in oil service life. The visualisation in Figure 5 shows a strong, unidirectional relationship between Contamination Index and % Water, with higher contamination levels following increases in water content. This pattern indicates that both parameters change simultaneously and represent an interrelated oil-degradation mechanism.

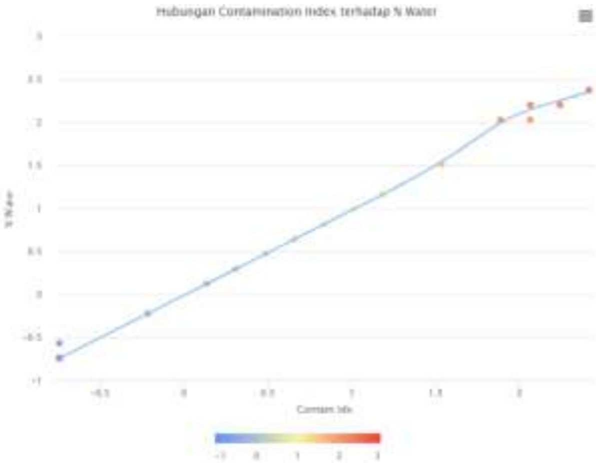

Figure 5. Visualisation of the relationship between the Contamination Index and % Water

It is also similar to the relationship between DV Visc % and DV Visc 40°C in the figure, which shows a very strong, unidirectional relationship: an increase in viscosity percentage is associated with an increase in oil viscosity at 40°C. This pattern is consistent with the 0.929 positive correlation in the correlation heatmap, indicating that the two parameters represent interrelated oil viscosity characteristics. This relationship indicates that changes in relative and absolute viscosity occur simultaneously during oil degradation.

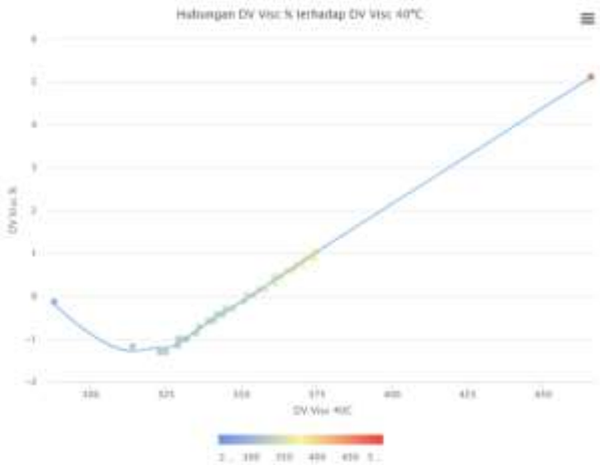

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Figure 6. Visualisation of the Relationship between DV Visc % and DV Visc 40ºC

The results of the correlation analysis indicate that several oil testing parameters exhibit stronger relationships with changes in Remaining Useful Life (RUL). The DV Visc 40°C and DV Visc (%) parameters exhibit the strongest negative correlation with RUL among the other parameters. It indicates that viscosity changes have the most significant relationship to reducing oil service life. In addition, the Contamination Index and % Water parameters show a tendency toward negative correlation, though with a lower level of influence. Therefore, viscosity can be prioritised as the primary indicator in oil condition monitoring, while contamination and water content serve as supporting indicators in preventive oil change decisions. This information can be put to practical use in maintenance activities by focusing oil condition monitoring on the parameters most sensitive to degradation. This approach supports the implementation of a condition-based maintenance strategy, allowing for early identification of potential failures and more effective oil change planning.

Furthermore, the results of this analysis can also serve as a basis for evaluating oil change intervals. If the operating time has exceeded the company's standard of 500 working hours, oil changes are recommended. However, if the service life exceeds this limit but the oil is still in good condition, replacement can be postponed while continuing to monitor critical parameters. Conversely, if the operational time has not reached 500 hours but the parameters show significant deviations, replacement can be considered based on actual conditions. To improve decision-making accuracy, further research using a more comprehensive RUL prediction model is urgently needed.

The results of this study are consistent with several previous studies on the analysis of oil conditions and Remaining Useful Life (RUL). Research by Chokelarb et al. (2024) found that changes in oil quality parameters, especially viscosity, are significantly associated with estimated remaining lubricant life, consistent with this study's findings that DV Visc 40°C and DV Visc (%) exhibit the strongest negative correlation with RUL. In addition, Harahap et al. (2022) explained that increasing water content in lubricants accelerates the oxidation and degradation of additives, consistent with the negative correlation between % Water and RUL. (Pujono & Nur Fauzi, 2020) emphasised that contamination in the lubrication system accelerates component wear; this finding is reinforced in the context of this study by the negative relationship between the Contamination Index and RUL. Furthermore, (Subhaktiyasa et al., 2025) emphasised that correlation analysis in quantitative research is effective for identifying the strength and direction of relationships among numerical variables, which supports the use of Pearson's correlation in this study as an exploratory approach to identify dominant parameters. Thus, the results of this study are consistent with the recent literature, which indicates that viscosity and contamination levels are important indicators of lubricant degradation and remaining service life.

CONCLUSION

This study aims to analyse the relationship between oil testing parameters and the Remaining Useful Life (RUL) of oil in chain bucket elevator gearboxes based on oil testing data obtained from the Maintenance Reliability Unit Laboratory of PT. Semen Padang. The analysis was conducted using the Pearson correlation method, with the data first normalised, then analysed using a correlation matrix and visualised as heatmaps and supporting graphs.

The analysis results show that viscosity parameters have the strongest relationship with RUL, with DV Visc 40°C and DV Visc % each showing negative correlations of -0.741 and -0.658, respectively. The Contamination Index and % Water parameters also show a negative correlation to RUL of -0.255, thus acting as supporting factors for oil degradation. In addition, there is a very strong positive correlation between several oil testing parameters, namely between Contamination Index and % Water (0.999) and between DV Visc % and DV Visc 40°C (0.929), indicating that these parameters change simultaneously and reflect interrelated oil degradation mechanisms. However, despite the positive correlation between each other, these parameters still show a negative correlation with RUL, confirming that collective changes in oil testing parameters reduce oil service life.

This study has several limitations, including the relatively limited data set: only 50 data points covering one unit of a chain bucket elevator gearbox at Cement Mill in Indarung VI, PT. Semen Padang, as well as variations in operating conditions that have not been fully represented. In addition, the analysis is still limited to linear relationships between variables using Pearson's correlation, so it has not considered the possibility of nonlinear relationships or the dynamics of oil degradation over time. Further research is recommended to use a larger amount of data, involve several equipment units, and combine correlation analysis with advanced modelling approaches to obtain a more comprehensive understanding of oil degradation and RUL determination.

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