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The Investigation of Additional Cooling Fan on the Brake System to Overcome the Overheating Issue: A Case Study of Oil Cooler Retarder Brake

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ABSTRACT

The retarder brake is a critical component for articulated trucks, particularly in coal mining, where heavy loads are transported on steep terrains. The primary braking system often proves inadequate under these conditions, making the retarder brake essential. However, overheating in the retarder brake system reduces braking efficiency and increases the risk of mechanical failure. This study investigates the causes of overheating and assesses the effectiveness of adding a fan cooler to the oil retarder brake system. The methodology employed is quantitative observation, where a fan cooler was installed in the cooling line before the oil entered the retarder cooler. Data were collected during vehicle operations on a steep slope, with retarder oil temperatures measured before and after fan installation. The results show a temperature reduction from 120 °C to 108 °C after installing the fan cooler, significantly improving the cooling efficiency. Furthermore, the fan cooler installation reduced the vehicle's breakdown unscheduled (BUS) time from 40 hours to just 2 hours. These findings suggest that adding a fan cooler prevents overheating and enhances the reliability and safety of braking systems in heavy-duty mining vehicles. Future studies could focus on integrating more excellent fan systems with enhanced pump capacity to optimize thermal management further.

INTRODUCTION

The demand for transportation services for heavy equipment and the mining industry has increased significantly to maintain competitiveness in local and global markets (Türkay & Akçay, 2014). Scania trucks, such as the Scania P460, R580, and R620, are commonly used for mining transportation, particularly for coal hauling in Indonesia's mining industry (Henriksen, T. E., 2022). Moreover, due to their intensive

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use, a regular maintenance system must be implemented to prevent premature failures and frequent breakdowns of vehicles in operation (Li & Fu, 2021). In recent years, brake failure accidents have increased, with the primary causes being harsh terrain and frequent operations (Samin et al., 2018). Additional brakes, such as exhaust and retarders, have been applied to avoid these issues, yet overheating remains a persistent weakness (Anjankar, 2023). Therefore, this study aims to investigate the overheating problem by adding a fan cooler to the oil retarder brake system (Pipit Muliyah et al., 2020).

A retarder brake is an auxiliary braking system used in heavy vehicles, particularly trucks and buses, designed to enhance braking power (Chen et al., 2022). This system operates by slowing down the rotation of the transmission output or the propeller shaft (Vigliani et al., 2021). Retarder brakes are typically integrated into the vehicle's transmission system, directly connected to the input propeller shaft. Retarder brakes help assist the primary braking system when descending hills with heavy loads (Kharazian et al., 2024). They provide better control for the driver, especially on steep roads during emergency braking situations (Mohd Shah et al., 2021). Retarder brakes include hydraulic retarders, electric retarders, and hydrodynamic retarders (Jiao et al., 2014). A hydraulic retarder is a braking system between the transmission and the propeller shaft. When activated, oil is pushed into the rotor and stator, creating pressure that slows the rotation of the propeller shaft. Engine power is automatically limited, and speed is reduced (Liu et al., 2015). An electric retarder operates based on the principle of electromagnetic induction. This system also consists of a rotor and stator, which generate a magnetic field to slow the rotation of the wheels (Lei et al., 2017). A hydrodynamic retarder is an auxiliary braking system that utilizes the principle of a torque converter, consisting of an impeller, turbine, and stator. When the retarder is activated, the impeller drives the oil, causing torque to resist wheel rotation (Mei et al., 2020). The torque generated by the hydrodynamic retarder can be adjusted according to the driver's needs. The voith retarder is one of the well-known hydrodynamic braking systems used in various utility vehicles (Scania, 2016).

The operation of the retarder brake system involves an oil pump that directs oil into the rotor and stator housing to increase pressure, thereby impeding the rotation of the propeller shaft (Sinimaa, 2022). When centrifugal force occurs, the rotor is slowed down as its cross-section fills with oil (Wang et al., 2016). This resistance leads to an increase in temperature. If the temperature exceeds the tolerance limit (> 120 °C), it can cause leaks in weak components such as seals or gaskets (Zhang et al., 2023). Cooling systems like the oil cooler are crucial in helping to reduce the oil temperature within the retarder. As is known, the oil cooler works by circulating coolant through the oil cooler (Wang et al., 2021). However, due to the extreme conditions of mining roads, the coolant alone is insufficient to cool the retarder oil. Additional cooling systems, such as a fan cooler, are required to cool the coolant before it reaches the oil cooler.

Research on cooling systems indicates that selecting radiators, fan size, and power prevents overheating. The temperature cooling system layout always depends on each application's specific needs. Therefore, thermal management and system layout are essential in developing new powertrain options. A thorough assessment of all heat sources involved is recommended to identify the best thermal management system. If possible, the cooling system can be designed to target thermal efficiency with the lowest possible power consumption for compressors, pumps, and fans (Wang et al., 2023). Other research discusses the maintenance and repair of cooling systems and their components. The radiators' cooling system is divided into air and water. Damage to components can disrupt cooling systems, which can be identified through inspections of the damage. Common issues in cooling systems include thermostat failure and damage to fans, water pumps, radiator caps, and coolant hoses. Proper maintenance and regular repair of these components are essential for the cooling system to function effectively and extend the lifespan of its components (Legiman et al., 2014).

Additional research highlights the importance of cooling in engines, as overheating can cause damage due to excess heat, ultimately reducing the engine and component lifespan. Testing methods for diesel engine radiator cooling systems involve several variables, including different revolutions per minute (RPM)

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levels. These tests show that higher engine RPMs cause the radiator temperature to rise more quickly (Nurafandi et al., 2020).

Several previous research references conclude that an oil cooler and radiator alone cannot cool the retarder oil. Therefore, in this study, an additional cooling system using a fan cooler is necessary to lower the coolant temperature before it reaches the retarder. Installing the fan cooler will reduce the retarder temperature exceeding 120 °C on the descent at Kilometer 17 (KM 17). This study aims to evaluate the effectiveness of adding a fan cooler in enhancing the cooling performance of the retarder system and preventing overheating, which could lead to mechanical failure. This installation is expected to maximize the cooling process and ensure the reliability of the braking system in heavy-duty vehicles. The position of the hydraulic retarder is shown in Fig 1, which aims to help readers identify its location.

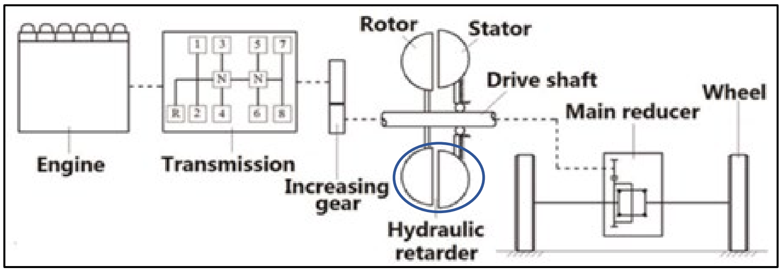

Fig. 1. Hydraulic retarder position (Liu et al., 2015).

METHODOLOGY

This study employed a quantitative method to investigate how adding a fan to the retarder brake system affects overheating issues. During maintenance, direct surveys were conducted on the coal transportation unit (prime mover) PM1013. This study also monitored the retarder brake system during descent at KM 17, covering a distance of 1.5 KM with a slope angle ranging from 25° to 35°. This location serves as a reference point for measuring the temperature of the retarder brake. During this operation, if overheating occurs, an analysis is carried out to identify the causes of the disruption.

Additionally, this study referred to previous laboratory studies that tested variations in pump capacity increases of 10%, 30%, and 50% at an ambient temperature of Tot = 313 K (40 °C). An increase in pump capacity by 50% was shown to reduce the oil temperature by approximately 12 °K; thus, enhancing cooling capacity is essential in improving the retarder system in this study (Jamroziak et al., 2019).

Although Jamroziak et al. (2019) used Kelvin (°K) as the unit, this study used degrees Celsius (°C) for consistency with the measurements conducted in the field. The temperature change of 12 °K reported in that study is equivalent to 12 °C, so this difference in temperature units does not affect the analysis results.

The tools used in this research include survey instruments, computers, thermoguns, hoses, cooling fans, and steel plates. Survey instruments involve creating questionnaires or interviews with drivers regarding the frequency of overheating issues in the retarder brakes. Computers are utilized to input data before and after repairs, while thermoguns are employed to measure temperatures before and after repairs accurately. The materials used consist of hoses, cooling fans, and steel plates.

The steps of the damage analysis process are presented in Fig 2. The red and green lines in the figure indicate the process paths in the disruption analysis. The green line represents the process path when an

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error or problem is found, followed by subsequent steps. Conversely, the red line indicates the process path when no errors are detected in the initial case, thus proceeding to the next case in the analysis.

The process begins with checking the breather to determine its condition. This process dictates the action to be taken when the breather is clogged with sludge. Next, inspect the oil cooler. Excellent system repairs are implemented if the oil cooler cannot cool the retarder. The retarder oil leakage is checked through the gasket area, and the oil level is verified. Repairs and actions must be taken on the oil cooler if leakage is found. Finally, a general performance test is conducted after completing all these processes.

Data collected during temperature measurements and interviews will be analyzed to compare the temperatures before and after repairs and to identify the causes of overheating in greater detail. The results of this data analysis are explained in detail in the Results and Discussion section. By completing this process, damage analysis and proposed solutions are presented, including examining overheating and analyzing leakage and component wear.

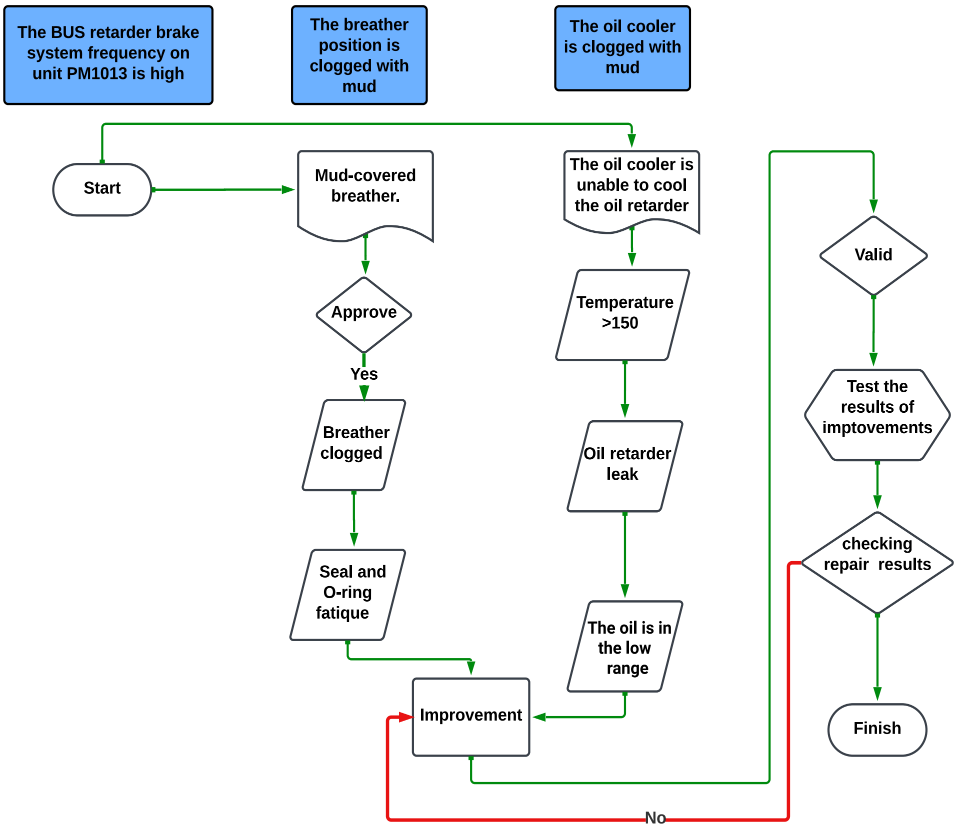

Fig. 2. Flowchart for checking and improvement process.

RESULTS AND DISCUSSION

Based on the analysis presented in Tables 1, 2, and 3, it is concluded that overheating in the retarder brake can lead to leaks in the retarder, resulting in a decrease in retarder oil levels and potentially damaging the

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propeller shaft seal. The travel recording from KM 32 to KM 28 (Fig 3, retarder oil temperature KM 32-28) indicates disturbances in braking performance, necessitating troubleshooting as detailed in Tables 1, 2, and 3. Reconditioning of unit PM1013 was conducted, which included repositioning the breather, as illustrated in Fig 4, Fig 5, and Fig 6. The graph presented in Fig 7 displays the recorded data of time and temperature during testing at KM 17, both before and after the installation of the fan cooler. Additionally, modifications were implemented by installing an auxiliary fan cooler within the retarder brake system, as depicted in Fig 8, Fig 9, and Fig 10. The selection of KM 17 as the testing site was due to its steeper incline compared to KM 32-28, providing a more challenging environment to evaluate the effectiveness of the modifications made to the retarder brake system.

Table 1. Analysis of breather functionality and lubrication issues in the retarder brake system

Process	Lubrication			
Factor	Material	Machine	Method	System
WSHB (what should happen)	The breather is not clogged.	The oil level is within the specified range of 7.9 liters.	The retarder oil is replaced every 2000 operating hours.	Maintaining the electric harness of the retarder by the HEEM (Heavy Equipment Electrical) standard.
WAH (what actually happened)	The retarder breather is clogged.	The oil level is in the low range.	The retarder oil is replaced every 2000 operating hours.	Maintaining the electric harness of the retarder by the HEEM standard.
Documentation of lubrication components				
Information	Bad condition	Bad condition	Good condition	Good condition

Table 2. Evaluation of solenoid functionality and temperature-related lubrication issues in the retarder

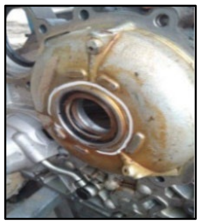
Process	Lubrication			
Factor	Machine	Machine	Machine	Material
WSBH	The retarder solenoid is functioning correctly.	The retarder oil temperature is within the range of 60 °C - 95 °C.	The retarder uses ATF (automatic transmission fluid) oil specifications.	The condition of the retarder seals and O-rings is elastic.
WAH	The retarder solenoid can open and close the valve in the retarder, which indicates it is functioning correctly.	The retarder oil temperature is above 150 °C.	The retarder uses ATF oil specifications.	The condition of the retarder seals and O-rings is hardened (fatigue).
Documentation of lubrication conditions	-	See Fig 3 for temperature retarder oil		
Information	Good condition	Bad condition	Good condition	Bad condition

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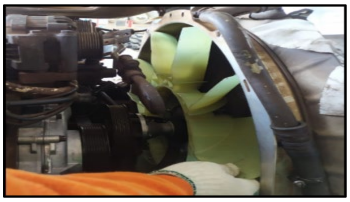
Table 3. Analysis of retarder cooling conditions

Process	Cooling	
Factor	Machine	Method
WSH	The oil cooler is in good condition.	Mandatory cooling system
WAH	The oil cooler is covered in mud.	A mandatory cooling system is implemented.
Documentation of cooling system conditions		
Information	Bad condition	Good condition

Further analysis indicates that one of the leading causes of increased temperature in the retarder is the clogging of the breather, leading to an increase in temperature in the retarder. The oil cooler covered in mud also worsens the situation, as the cooling system cannot effectively cool the oil. The oil temperature exceeding 150 °C, far above the safe range of 60 °C – 95 °C, accelerates material fatigue in the seals and O-rings, eventually causing leaks (Wang et al., 2023). The detected drop in retarder oil level also indicates inadequate lubrication, increasing the risk of damage to other components, such as the propeller shaft seals. Therefore, stricter maintenance of the breather and oil cooler, along with regular monitoring of the oil level, is essential to prevent the recurrence of this overheating issue.

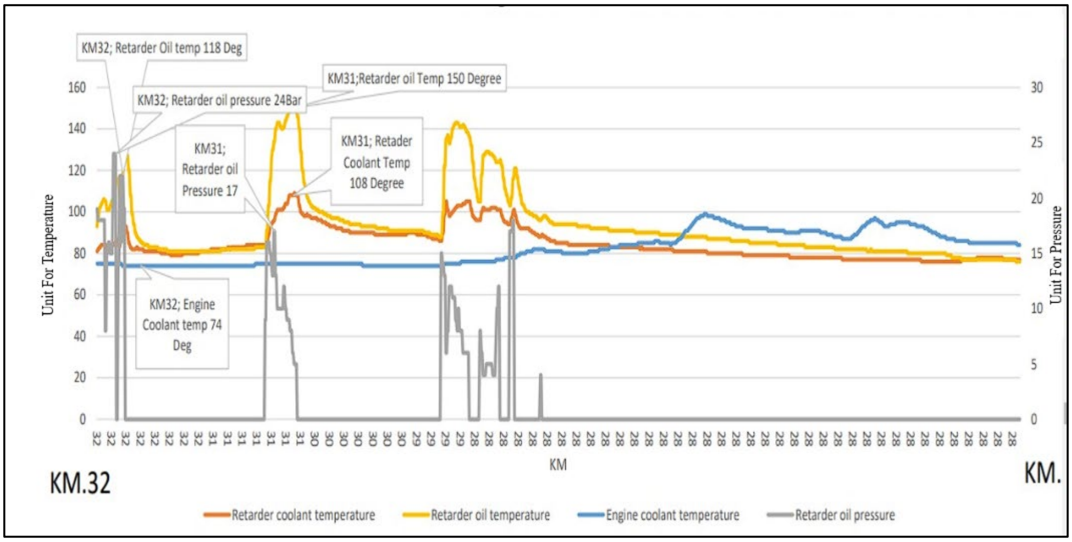


Fig. 3. Temperature retarder oil at KM 32-28.

The experiment for testing the modifications was conducted at KM 17, as this location has a steeper incline than KM 32-28, providing a more challenging environment to evaluate the effectiveness of the modifications made to the retarder brake system.

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Checking the cause of breakdown

Next, the analysis was conducted based on the data presented in Table 4 to identify the underlying reasons for the breakdown. It was found that the breather was obstructed by mud, preventing hot air from escaping from the retarder and resulting in a temperature increase. Additionally, overheating was exacerbated by an inadequate oil cooler, which failed to effectively reduce the temperature of the retarder oil. These findings highlight the complex system dynamics contributing to the observed breakdown.

Table 4. Checking the causes of breakdowns

Main problem				
The high frequency of the breakdown unscheduled (BUS) retarder brake system on prime over (PM) 1013.				
No	Road cause	Documentation	Validation	Recommendation
1	Breather clogged	 	The retarder breather is covered in mud, which can lead to seal damage. Checking method visual observation.	Need improvement
2	The oil cooler cannot cool the oil retarder and is clogged with mud.		The oil cooler cannot adequately cool the oil retarder due to insufficient cooling capacity. Checked by SDP3 tool and visual observation. (Multy version 22.120.0.0)	Need Improvement

Determination of improvements

This section examines the measures to be taken during the repair process, considering both the cost and the effectiveness of temperature reduction. Table 5 shows indicators for specific aspects related to these measures. The analysis of the fundamental problem, in this case, is presented in Table 6, which suggests the following steps: replacing the breather, repositioning the breather, and installing a fan cooler. The

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analysis shown in Table 6 is based on the selection of costs and the effectiveness of corrective actions outlined in Table 5.

Table 5. Price level and classification

Ease level (I) and scale	Classification (I)	Effectiveness level and scale	Lead time level (II) and Scale	Classification (II)	Cost and scale
Very easy (5)	Availability of supporting items/parts.	Highly effective (5)	Very fast (5).	Completion (<1 week).	Rp.0 - Rp. 1.000.000 (5).
Easy (4)	Availability of supporting items (indent 1-7 days).	Effective (4)	Fast (4).	Completion (1 week).	Rp. 1.000.000 – Rp. 3.000.000 (4).
Fairly difficult (3)	Availability of items/parts (1-2 weeks).	Moderately effective (3)	Quite fast (3).	Completion (1-2 weeks).	Rp. 3.000.000 – Rp. 6.000.000 (3).
Difficult (2)	Availability of supporting items (2-4 weeks).	Not effective (2)	Slow (2).	Completion (2-3 weeks).	Rp. 6.000.000 – Rp. 10.000.000 (2).
Very difficult (1)	Availability of supporting items (>1 month).	Highly ineffective (1).	Very slow (1)	Completion (3 weeks).	>Rp. 10.000.000 (1).

Table 6. Determining the repairs

The root cause of the problem	Alternative improvement ideas	Action plan	Analysis					
			Ease (1-5)	Effectiveness (1-5)	Time (1-5)	Cost (1-5)	Total	*Conclusion
1. The retarder breather lacks a strainer.	(1) Installation of a strainer.	Installing a strainer on the breather piping.	2	2	3	5	12	NS
	(2) Replacing the breather.	Using a mushroom breather.	4	4	5	4	17	S
2. The retarder breather is located below.	(1) Repositioning the breather.	Positioning the breather to avoid mud exposure.	5	4	4	5	18	S
3. The oil cooler is prone to mud blockage.	(1) Adding cooling to the cooler.	Installation of a fan on the oil cooler.	2	5	4	4	15	S
	(2) Changing the oil cooler.	Replacing the oil cooler with a fan and repositioning.	3	2	3	4	12	NS

*NS = not selected; S = Selected

Implementation of improvements

After analyzing the cause of the problem, in this section, the repair steps are implemented as follows.

Breather replacement and repositioning position

Before the repair, the retarder breather channel is directed downwards, often causing problems with the breather being blocked by mud. This condition obstructs the airflow, preventing air from escaping the retarder. Therefore, the repair is done by replacing the breather, as shown in Fig 4 and Fig 5. Initially, a standard pipe is replaced with a mushroom breather to prevent breather blockage by mud. This reference is taken from Multy TI – 0518 05 (Bonebrake, 1988).

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After the repair, mud no longer blocks the air channel, preventing any blockages in the retarder. The seal's lifetime increases, and there are no more leaks. The highly challenging hauling road conditions cause mud buildup at the bottom, covering the mushroom breather. This results in poor breather circulation, preventing hot air from escaping the retarder. To overcome this obstacle, an additional repair is carried out by adding a longer hose, as seen in Fig 6. This hose is added to relocate the breather to the rear of the cabin to avoid mud exposure. This repair has yielded satisfactory results as the breather no longer experiences blockages due to mud. This repair has also extended the interval for replacing retarder seals to HM (hours meter) 2500.

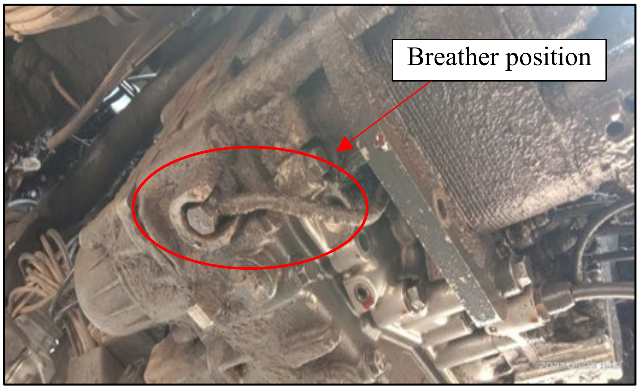

Fig. 4. The initial position of the breather.

Fig. 5. The position after breather improvement.

Installation of extra fan cooler retarder before oil cooler

Installing the fan cooler aims to cool the coolant flowing towards the retarder oil cooler, which cools the retarder oil. Before the repair, the retarder consistently experienced overheating, especially on extreme downhill roads. The frequent overheating led to unscheduled breakdowns. As shown in Fig 7, the coolant temperature rises to 120 °C on downhill slope KM 17. This temperature range approaches the overheating limit of 150 °C.

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Fig. 6. (a) and (b) Before breather repositioning; (c) and (d) after breather repositioning.

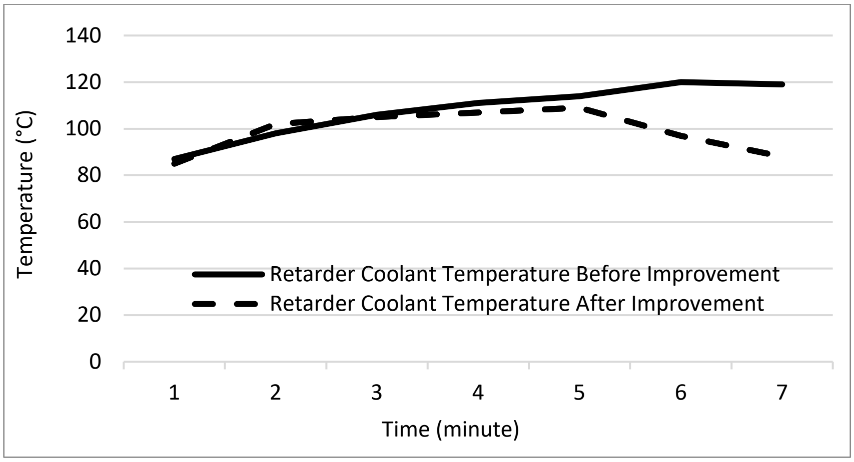

Fig. 7. Graph of the retarder before improvement.

The repair process includes several points as follows:

1. Design of additional lines created between the output hose coolant channel towards the input of the oil cooler. The aim is to facilitate the installation and determination of additional lines for the placement of the fan cooler. The installation of this setup is detailed in Fig 8.

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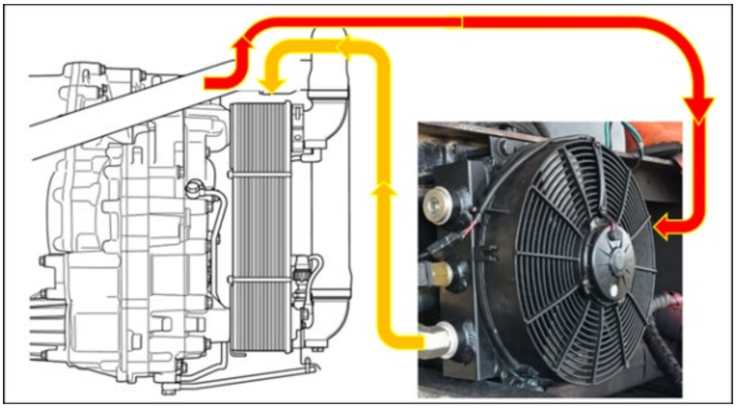
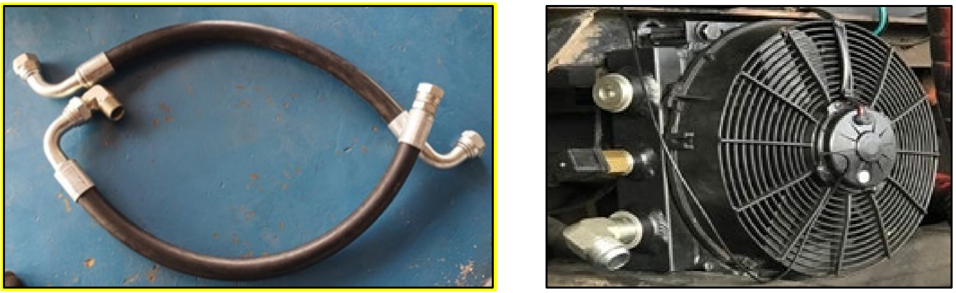


Fig. 8. The design of the pathway for the additional fan cooler.

2. The equipment required for the repair, as shown in Fig 9, includes the O.K.O. 25-1 G.T. cooling fan. This aluminum fan has a working temperature range of -20 °C to +80 °C and a working pressure of 26 bar (static).



(a) (b)

Fig. 9. (a) Hose and (b) fan cooler components.

3. Fig 10 shows the installation of an additional cooler in the retarder cooling line. This process is carried out to connect the cooler to the retarder cooling line. The process is considered complex because the more relaxed line is densely packed with frame structures on the unit.

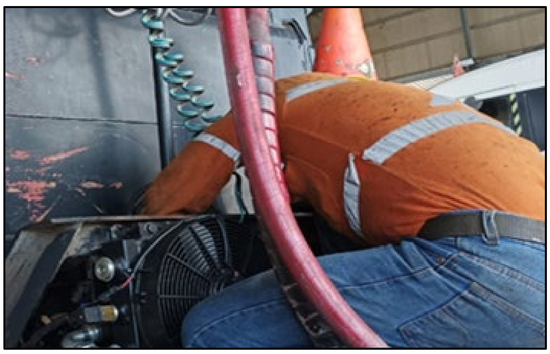


Fig. 10. Installation of the additional fan cooler.

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4. The installation of the fan controller, as seen in Fig 11, aims to regulate the operation and non-operation of the fan using a coolant temperature sensor that can be adjusted through the controller. The applied setting activates when the coolant temperature reaches 90 °C and deactivates when the coolant temperature drops below 87 °C.

Fig. 11. Temperature controller.

5. Fig 12 illustrates the installation of the electrical control circuit, utilizing a 24 V battery connected to the relay switch (R94). A 12 V battery powers the relay and functions to connect the 24 V power supply to the fan cooler in the retarder brake system. This system is designed to efficiently distribute power to the temperature control line and relay, with different voltage outputs. The circuit automatically activates and deactivates the system based on the set temperature. Temperature data for the oil and coolant is collected through sensors on the unit, which are monitored from the cabin.

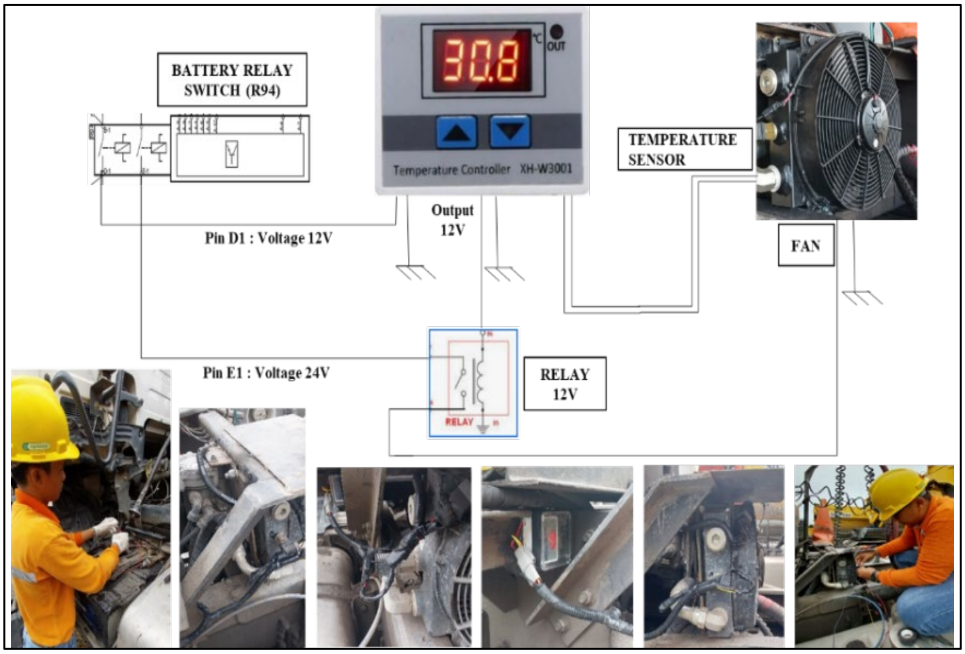

Fig. 12. Electrical line installation.

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Improvement results

A laboratory study on retarder brake cooling using variations in pump capacity addition of 10%, 30%, and 50% at a temperature around Tot = 313 K (40 °C). The research results are presented in Fig 13. The experiment used glycol as the cooling medium. The addition of 50% pump capacity resulted in a decrease in oil temperature of approximately 12 °K. The experimental results indicate that to decrease the temperature in the retarder cooling system, the pump capacity should be increased by 50% (Jamroziak et al., 2019).

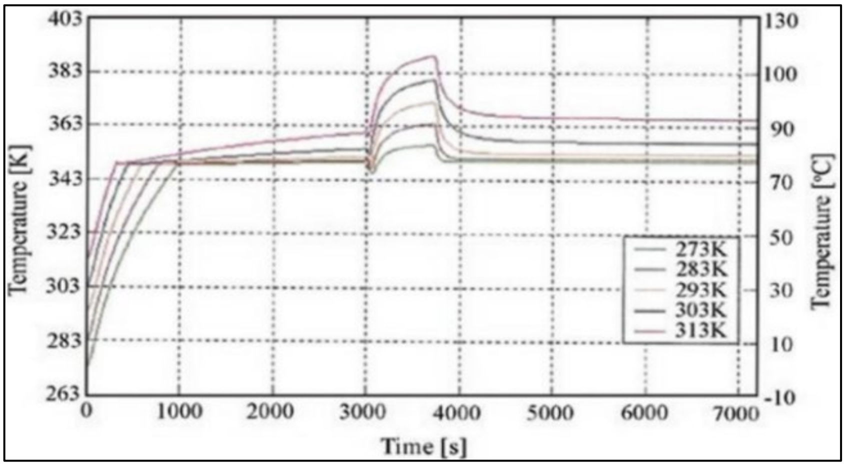

Fig. 13. shows the trend of coolant temperature.

In contrast to the study by (Jamroziak et al., 2019), this experiment was conducted with a specially designed fan cooler to enhance excellent cooling. The primary function of the fan cooler is to increase the cooling of the retarder oil to prevent overheating. The effectiveness of this method is shown in Fig 14. In Fig 14, there is a reduction in the retarder coolant temperature to 108 °C during the descent at KM 17. The total unproductive time has significantly reduced from 40 hours to just 2 hours. These results ensure that the retarder braking system can be utilized to its maximum potential without experiencing temperature spikes beyond the critical overheating limit (>150 °C).

This demonstrates a significant advancement compared to conventional methods, such as increasing coolant pump capacity, as discussed in previous literature (Jamroziak et al., 2019). While increasing coolant pump capacity may offer some reduction in oil temperature, it may not provide as substantial a decrease as implementing a fan cooler. Moreover, reducing unproductive time from 40 hours to just 2 hours highlights the practical benefits of employing advanced cooling technologies like the fan cooler in heavy-duty vehicle applications.

Therefore, the results from this study strongly support the recommendation for further development and implementation of fan-more-excellent systems in retarder braking systems for heavy-duty vehicles. Such systems effectively address overheating issues, enhance operational efficiency, and reduce downtime, ultimately contributing to safer and more reliable vehicle operation.

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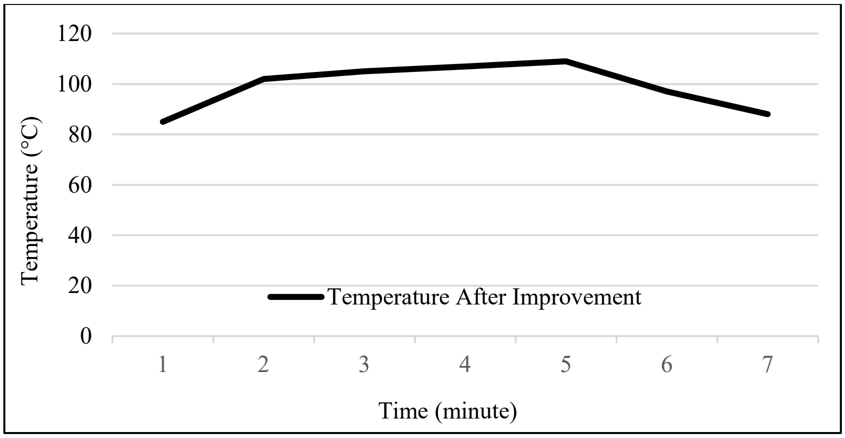

Fig. 14. Graph of the retarder after improvement.

CONCLUSION

This research demonstrates that installing an additional fan cooler in the retarder brake system significantly reduces overheating, improving the braking performance of heavy vehicles in mining operations. Installing the O.K.O. 25-1 G.T. fan cooler successfully lowered the oil temperature from 120 °C to 108 °C without requiring increased pump capacity. However, laboratory tests indicated that a 50% increase in pump capacity could reduce the oil temperature by approximately 12 °C, making both methods viable for enhancing thermal management in the braking system. The fan cooler has proven more efficient, reducing temperature and decreasing breakdown unscheduled (BUS) from 40 hours to just 2 hours, even on steep terrain. This allows the braking system to operate more safely and reliably when carrying heavy loads. Adding the fan cooler and increasing pump capacity are crucial in improving the cooling system of heavy vehicle retarder brakes. Further development regarding integrating both could enhance the cooling system's efficiency and effectiveness, supporting operational efficiency and safety.

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AUTHORS' CONTRIBUTIONS

The authors confirm their contributions to the paper as follows: study conception and design by Imam Sholihin, Gusti Dimas S.; data collection by Maulana Haydil Rahmadanur; analysis and interpretation of results by Maulana Haydil Rahmadanur, Achmad Fauzan Hery Soegiharto, Muhammad Syafiq; draft manuscript preparation by Maulana Haydil Rahmadanur, Achmad Fauzan Hery Soegiharto. All authors reviewed the results and approved the final version of the manuscript.

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CONFLICT OF INTERESTS STATEMENT

All authors declare that they have no conflicts of interest.

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