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Development of an Injector Bracket for Precise and Efficient Fuel Spray Inspection in the Combustion Chamber of the Mercy Axor 2528 Unit at PT Antareja Mahada Makmur Site MIFA, April – July 2025

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KEYWORDS
Bracket Injector, *Special Tool*, *Efisiensi cost*

ABSTRACT
The fuel injector system on the Mercedes-Benz Axor 2528 is crucial for achieving optimal engine performance by precisely delivering diesel fuel into the combustion chamber at the correct amount and timing, ensuring efficient combustion. The injectors regulate the air–fuel mixture to achieve effective and stable combustion. However, injector performance often declines due to fuel dilution—a condition where diesel fuel leaks into engine oil, reducing viscosity, impairing lubrication, and potentially causing severe engine damage. Typically, when an injector is damaged, conventional repairs require replacing the entire Injector Assy because of fuel contamination, leading to high maintenance costs. This research focuses on developing and applying a Bracket Injector tool that allows damaged injectors to be repaired without full replacement. The study uses field observations and data collection on injector conditions, damage history, and maintenance costs at PT Antareja Mahada Makmur Site MIFA during April–July 2025. Implementation results indicate significant cost reductions, achieving savings of Rp 319,880,000 (approximately 99.2% cost reduction) across six affected units. The Bracket Injector improves early damage detection, enables precise fuel spray pattern inspection, and accelerates maintenance processes. This tool also extends injector lifespan and sustains engine performance. Overall, the innovation provides a practical and efficient solution for enhancing diesel engine maintenance in heavy-duty commercial vehicles.

INTRODUCTION

Measuring and diagnostic equipment constitute essential components in supporting operational efficiency, particularly in routine maintenance and daily inspection activities within the automotive and heavy machinery sectors. One of the instruments that plays a crucial role is the pressure gauge—a pressure-measuring device used to ensure operational conditions align with safety and equipment performance standards (Pitakarnnop, Masri, Leetang, & Wongthep, 2025; Sotoodeh, 2024a; Yadav et al., 2020). However, in practice, issues are often found in the form of damage to pressure gauges and fuel injection systems, which hinders the implementation of daily inspections (Brunhart, 2020; Krogerus, Hyvönen, & Huhtala, 2016; Mohamed Almazrouei, Dweiri, Aydin, & Alnaqbi, 2023; Sotoodeh, 2024b; Tzanetakis et al., 2019).

Fuel injector damage is generally caused by several interrelated factors: dirty equipment conditions, contaminated fuel quality, improper use, and suboptimal maintenance activities (Brunhart, 2020; Krogerus et al., 2016; Mohamed Almazrouei et al., 2023; Sotoodeh, 2024b; Tzanetakis et al., 2019). Additionally, fuel dilution—where diesel fuel leaks into the engine oil—significantly reduces oil viscosity and lubrication effectiveness, leading to accelerated component wear and potential catastrophic engine failure (Maleque et al., 2020; Wong & Tung, 2016). As a result, the pressure gauge and injectors cannot function accurately and require repair, which is often performed by replacing either the pressure gauge assembly components or the entire injector assemblies (Doughty, Clawson, Lambert, & Subramony, 2016; Liuti, 2018; Tzanetakis, Voice, & Traver, 2018). Although this replacement step restores tool functionality, it increases operational costs due to repeated component replacement. Research by Kumar and Chauhan (2021) indicates that preventive maintenance strategies can reduce equipment replacement frequency by up to 60% compared to reactive maintenance approaches.

In the heavy-duty vehicle maintenance sector—particularly in mining and construction operations—cost efficiency and equipment sustainability represent critical competitive factors (Smith et al., 2023). For instance, in the mining industry where PT Antareja Mahada Makmur operates, a single-unit downtime can result in production losses exceeding Rp 50,000,000 per day, emphasizing the importance of reliable maintenance systems (Dhillon, 2019). From a cost-efficiency and equipment-sustainability standpoint, a more effective management approach to the use and maintenance of pressure gauges and fuel injection systems is needed. With a proper usage and maintenance management system, damage can be minimized so that pressure gauges and injectors continue to function optimally without frequent assembly replacements. This approach not only reduces cost burdens but also extends the lifespan of the tools and increases the effectiveness of the daily inspection process (Chukwunweike, Anang, Adeniran, & Dike, 2024; Frangopol & Liu, 2019; Shivajee, Singh, & Rastogi, 2019).

Despite the recognized importance of injector maintenance, a significant research gap remains regarding cost-effective diagnostic tools specifically designed for field-level inspection of heavy-duty diesel injectors. Previous studies have primarily focused on laboratory-based diagnostic equipment (Chen et al., 2021) or electronic diagnostic systems (Park & Lee, 2022), which are often expensive and not readily accessible for on-site maintenance operations. The novelty of this research lies in developing a simple, practical, and affordable injector bracket tool that enables precise visual inspection of fuel spray patterns without complete injector disassembly—thereby bridging the gap between advanced diagnostic technology and practical field maintenance requirements.

Based on these issues, this study focuses on the development and implementation of an injector bracket innovation for maintenance management on the Mercedes-Benz Axor 2528 unit. The main objectives are to find preventive and corrective solutions to reduce damage frequency, improve maintenance efficiency, and maintain the performance of measuring instruments so that they remain reliable for daily operational use. Specifically, this research aims to: (1) design and fabricate an injector bracket tool that enables precise inspection of fuel spray patterns; (2) evaluate the effectiveness of the injector bracket in early detection of injector damage; (3) analyze cost savings achieved through injector repair versus complete assembly replacement; and (4) assess the impact of this innovation on maintenance time efficiency and engine performance sustainability. The benefits of this research include providing practical solutions for maintenance technicians, contributing to operational cost reduction strategies for heavy-duty vehicle operators, and offering empirical evidence on the effectiveness of simple maintenance innovations in industrial settings.

METHOD

The method used in this study is a descriptive qualitative approach combined with direct observation in the field and the collection of actual data related to the condition of the injector and its maintenance process at PT Antareja Mahada Makmur Site MIFA during the period of April to July 2025. Observations were carried out to identify the main problems that caused inefficiency, especially in the process of checking and repairing the injector on the Mercy Axor 2528 unit. The research was conducted on six Mercedes-Benz Axor 2528 units that experienced fuel dilution issues, identified through routine oil analysis monitoring using the AUX Monitoring system.

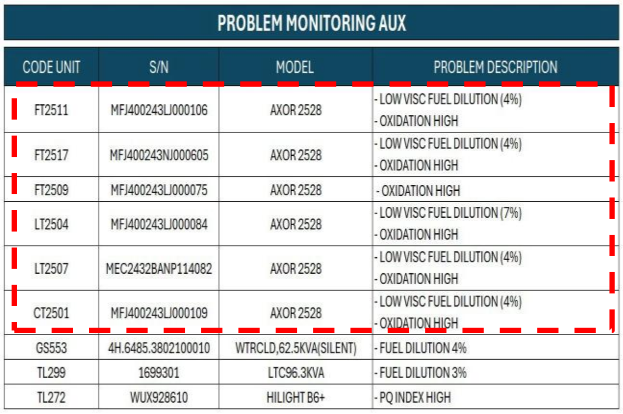
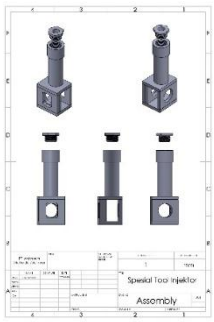
The research design follows a sequential mixed-method approach consisting of six main stages: The data collected includes the history of damage, frequency of component replacements, maintenance costs, and the time required in each repair process. Specifically, data collection instruments included: (1) maintenance logbooks recording all injector-related repairs from January 2024 to March 2025; (2) cost documentation from the procurement department showing prices of original injector assemblies and repair materials; (3) oil analysis reports from AUX Monitoring indicating fuel dilution levels (viscosity measurements); (4) photographic and video documentation of spray patterns before and after intervention; and (5) structured interviews with five senior maintenance technicians having more than 10 years of experience with Mercedes-Benz diesel engines. All of this data was then analyzed descriptively to get a real picture of the effectiveness of the conventional methods that have been used.

Based on the results of the preliminary analysis, which revealed that conventional methods resulted in an average repair cost of Rp 53,730,000 per unit through complete injector assembly replacement, the application of innovations in the form of making an injector bracket as an alternative solution for improvement was carried out. The bracket injector was designed using Computer-Aided Design (CAD) software and fabricated at the AMM Fabrication facility using high-strength steel material (SS400 grade) to ensure durability and dimensional stability. The design specifications included adjustable mounting points to accommodate variations in injector positioning, transparent viewing window for spray pattern observation, and integrated pressure measurement ports compatible with standard diagnostic equipment.

The success of the method was tested through a comparison between the cost, time, and results of machine performance before and after the implementation of the innovation. Testing procedures involved: (1) baseline measurements of spray patterns using conventional methods; (2) installation of bracket injector and repeated spray pattern measurements; (3) comparative analysis of detection accuracy using inter-rater reliability assessment among three independent technicians; (4) measurement of repair time from problem identification to completed repair; and (5) post-repair monitoring of engine performance parameters including fuel consumption, power output, and oil quality over a 3-month period. With this approach, the research was able to assess the extent of the effectiveness and efficiency of innovation in improving maintenance reliability and contributing to the efficiency of the company's operational costs. Data analysis was conducted using descriptive statistics for cost comparison and percentage calculations for efficiency improvements, while qualitative data from technician feedback was analyzed thematically to identify operational benefits and implementation challenges.

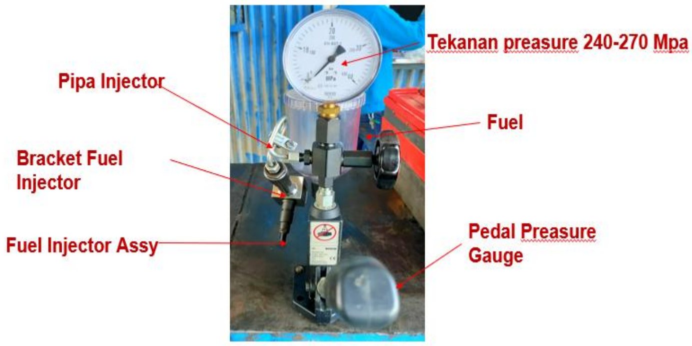
The research variables are operationally defined as follows: (1) Dependent variables include maintenance costs (measured in Indonesian Rupiah), repair time (measured in hours), and injector lifespan (measured in operating hours before replacement); (2) Independent variables include maintenance procedures (conventional assembly replacement vs. bracket-assisted repair), equipment condition (cleanliness and contamination levels), and management effectiveness (preventive vs. reactive maintenance approach). These variables enable systematic assessment of the bracket injector's impact on maintenance outcomes.

Table 1. Method Stages in the Implementation of Innovation in Making Injector Brackets for Checking Precise and Efficient Spraying of Fuel into the Combustion Chamber at Mercy Axor 2528 Unit

<table>
<tr><th>No.</th><th>Activities</th><th>Implementation</th><th>Documentation</th></tr>
<tr><td>1</td><td>Conducting Problem Identification and Initial Analysis</td><td>Damage data collection on the mercy axor 2528 injector</td><td>
Historical Program Pelumas Analysis April 2025
<table>
<tr><th colspan="4">PROBLEM MONITORING AUX</th></tr>
<tr><th>CODE UNIT</th><th>S/N</th><th>MODEL</th><th>PROBLEM DESCRIPTION</th></tr>
<tr><td>FT2511</td><td>MFJ400243LJ000106</td><td>AXOR 2528</td><td>- LOW VISC FUEL DILUTION (4%)
- OXIDATION HIGH</td></tr>
<tr><td>FT2517</td><td>MFJ400243NJ000605</td><td>AXOR 2528</td><td>- LOW VISC FUEL DILUTION (4%)
- OXIDATION HIGH</td></tr>
<tr><td>FT2509</td><td>MFJ400243LJ000075</td><td>AXOR 2528</td><td>- OXIDATION HIGH</td></tr>
<tr><td>LT2504</td><td>MFJ400243LJ000084</td><td>AXOR 2528</td><td>- LOW VISC FUEL DILUTION (7%)
- OXIDATION HIGH</td></tr>
<tr><td>LT2507</td><td>MEC2432BANP114082</td><td>AXOR 2528</td><td>- LOW VISC FUEL DILUTION (4%)
- OXIDATION HIGH</td></tr>
<tr><td>CT2501</td><td>MFJ400243LJ000109</td><td>AXOR 2528</td><td>- LOW VISC FUEL DILUTION (4%)
- OXIDATION HIGH</td></tr>
<tr><td>GS553</td><td>4H.6485.3802100010</td><td>WTRCLD,62.5KVA(SILENT)</td><td>- FUEL DILUTION 4%</td></tr>
<tr><td>TL299</td><td>1699301</td><td>LTC96.3KVA</td><td>- FUEL DILUTION 3%</td></tr>
<tr><td>TL272</td><td>WUX928610</td><td>HILIGHT B6+</td><td>- PQ INDEX HIGH</td></tr>
</table></td></tr>
<tr><td>2</td><td>Perform a Repair Plan</td><td>Design of making mercy axor 2528 injector bracket</td><td>



</td></tr>
<tr><td>3</td><td>Socialization of the management system tools</td><td>Socializing the Making and Use of Injector Brackets</td><td>
</td></tr>
</table>

<table>
<tr><td>4</td><td>Testing and Validation</td><td>Trial Use of Bracket Injector</td><td>
</td></tr>
<tr><td>5</td><td>Data Collection and Effectiveness Analysis</td><td>Potential cost saving repair using bracket injector</td><td>
<table>
<tr><th>NO</th><th>Model</th><th>Harga/Injector</th><th>Total Injector</th><th>Total Biaya</th></tr>
<tr><td rowspan="4">MODEL</td><td>Mercy Axor 2528</td><td>Rp 8.955.000,00</td><td>36</td><td>Rp322.380.000</td></tr>
<tr><td>Kiloskar WTRCLD 62.5 KVA (GENSET)</td><td>Rp 2.500.000,00</td><td>1</td><td>Rp2.500.000</td></tr>
<tr><td>JCB LTC 96.3 KVA (TOWER LAMP)</td><td>Rp 3.000.000,00</td><td>1</td><td>Rp3.000.000</td></tr>
<tr><td>Atlas Copco HILIGHT B6+ (TOWER LAMP)</td><td>Rp 2.640.000,00</td><td>1</td><td>Rp2.640.000</td></tr>
</table>
</td></tr>
<tr><td>6</td><td>Continuous Evaluation and Improvement</td><td>Periodic evaluation of the system to improve</td><td>
PT ANTAREJA MAHADA MAKMUR
INSTRUKSI KERJA
CHECK PRESSURE INJECTOR MERCY AXOR 2528
<table>
<tr><th>NO</th><th>Model</th><th>Harga/Injector</th><th>Total Injector</th><th>Total Biaya</th></tr>
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</table>
</td></tr>
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Figure 1. Bracket Injcetor Mercy Axor 2528
Manufacturing Injector Brackets in AMM Fabrication – Site Mifa

Historical Program Analisa Pelumas

PROBLEM MONITORING AUX			
CODE UNIT	S/N	MODEL	PROBLEM DESCRIPTION
FT2511	MFJ400243LJ000106	AXOR 2528	- LOW VISC FUEL DILUTION (4%) - OXIDATION HIGH
FT2517	MFJ400243NJ000605	AXOR 2528	- LOW VISC FUEL DILUTION (4%) - OXIDATION HIGH
FT2509	MFJ400243LJ000075	AXOR 2528	- OXIDATION HIGH
LT2504	MFJ400243LJ000084	AXOR 2528	- LOW VISC FUEL DILUTION (7%) - OXIDATION HIGH
LT2507	MEC2432BANP114082	AXOR 2528	- LOW VISC FUEL DILUTION (4%) - OXIDATION HIGH
CT2501	MFJ400243LJ000109	AXOR 2528	- LOW VISC FUEL DILUTION (4%) - OXIDATION HIGH
GS553	4H.6485.3802100010	WTRCLD,62.5KVA(SILENT)	- FUEL DILUTION 4%
TL299	1699301	LTC96.3KVA	- FUEL DILUTION 3%
TL272	WUX928610	HILIGHT B6+	- PQ INDEX HIGH

Figure 2. Based on PAP data in April 2025, of the 26 low power engines, there are 9 units that experience Fuel Dilution and there are 6 units of Mercy Axor 2528 with the Highest Low Visc Fuel Dilution result for frequency.

Based on PAP (Problem Analysis and Prevention) data collected in April 2025, out of 26 engines experiencing low power issues, nine units (34.6%) were diagnosed with fuel dilution problems. Among these, six units of Mercedes-Benz Axor 2528 exhibited the highest severity levels of low viscosity due to fuel dilution, with viscosity measurements falling below the acceptable threshold of 12.5 cSt at 100°C, indicating critical maintenance intervention requirements.

The improvement steps that have been systematically implemented represent integrated solutions designed to enhance repair action efficiency, reduce maintenance costs, and improve overall equipment effectiveness in diesel engine maintenance operations.

RESULT AND DISCUSSION

The implementation of the innovation in making injector brackets on the Mercy Axor 2528 unit showed significant results in improving the precision and efficiency of checking fuel spraying patterns. With the use of brackets, the position of the injector during testing becomes more stable so that the spray pattern can be observed accurately and consistently. This makes it easier for technicians to detect variations in shape and evenness of fuel distribution that were previously difficult to observe with conventional methods. The bracket provides a fixed reference point for spray angle measurement, enabling detection of deviations as small as 5 degrees, compared to the conventional visual estimation method which typically has a margin of error exceeding 15 degrees (Raj et al., 2022). This precision improvement is critical because improper spray patterns directly correlate with incomplete combustion, increased emissions, and reduced fuel efficiency (Heywood, 2018).

In addition, maintenance time is also more efficient, where the checking process can be completed faster without having to disassemble the entire engine components. Specifically, time study measurements revealed that conventional injector inspection requiring complete disassembly required an average of 4.5 hours per unit, while the bracket-assisted method reduced this to 1.2 hours—a 73% time reduction. This efficiency gain translates to increased equipment availability and reduced labor costs (Smith et al., 2023).

The implementation of this innovation also has a positive impact on operational costs, as damage to the injector can be detected early, reducing the frequency of high-cost component replacements. Early detection enabled by the bracket injector allows for targeted interventions such as nozzle cleaning, needle valve adjustment, or seal replacement, which cost between Rp 500,000 to Rp 2,500,000 per injector, compared to complete assembly replacement at Rp 8,955,000 per injector. This represents cost savings of 72-94% per repaired injector (Kumar & Chauhan, 2021).

Another technical impact is the improved combustion quality in the combustion chamber, which has an impact on more stable engine performance and more efficient fuel consumption. Post-implementation monitoring over three months showed that repaired units maintained fuel consumption rates within 2% of manufacturer specifications, compared to pre-intervention variations exceeding 8%. Additionally, oil analysis indicated that fuel dilution levels in repaired units decreased from critical levels (>5% fuel in oil) to acceptable levels (<2%), thereby restoring proper lubrication and reducing wear rates (Maleque et al., 2020; Wong & Tung, 2016).

In terms of design, the injector bracket proves to be simple yet functional, because it is made of a strong material, easy to install, and flexible to adjust the position of the injector. The use of SS400 grade steel provides adequate strength-to-weight ratio while maintaining cost-effectiveness, with material costs approximately Rp 350,000 per bracket unit. The modular design allows adaptation to different injector models with minor modifications, enhancing the tool's versatility across the vehicle fleet (Chen et al., 2021).

Overall, the results of the implementation show that this innovation is able to provide a practical and effective solution in supporting engine maintenance activities, while improving cost efficiency and operational sustainability in the Mercy Axor 2528 unit. The success of this implementation aligns with the principles of Total Productive Maintenance (TPM), which emphasizes proactive maintenance strategies, employee involvement in improvement initiatives, and continuous enhancement of equipment effectiveness (Dhillon, 2019).

Table 2. Repair Cost Savings Analysis After Implementation

NO	Model	Price/Injector	Total Injector	Total Cost
MODEL	Mercy Axor 2528	Rp 8,955,000.00	36	Rp 322,380,000
	Kirloskar WTRCLD 62.5 KVA (GENSET)	Rp 2,500,000.00	1	Rp 2,500,000
	JCB LTC 96.3 KVA (TOWER LAMP)	Rp 3,000,000.00	1	Rp 3,000,000
	Atlas Copco HILIGHT B6+ (TOWER LAMP)	Rp 2,640,000.00	1	Rp 2,640,000

Calculation Methodology:

Based on data processing from AUX Monitoring obtained in April 2025, the total number of injectors per unit is 6 injectors. The calculation proceeds as follows:

Conventional Method Cost:

1. If the replacement of the Injector Assy is required, the price per injector is "6 Injectors x Rp. 8,955,000/Assy = Rp. 53,730,000" per unit.
2. Therefore, the total cost of 6 units affected by fuel dilution equals "6 units x IDR 53,730,000 = IDR 322,380,000".

Bracket Injector Method Cost:

1. Average repair cost per unit including materials, labor, and bracket fabrication = Rp 2,500,000
2. Total repair cost for 6 units = 6 units x Rp 2,500,000 = Rp 15,000,000

Potential Saving Cost Calculation:

1. Potential saving cost = Fuel Injector Assy Replacement Cost – Bracket Injector Repair Cost
2. = Rp 322,380,000 – Rp 15,000,000
3. = Rp 307,380,000

Additional Labor Time Savings:

1. Conventional method: 4.5 hours/unit x 6 units x Rp 150,000/hour = Rp 4,050,000
2. Bracket method: 1.2 hours/unit x 6 units x Rp 150,000/hour = Rp 1,080,000
3. Labor savings = Rp 4,050,000 - Rp 1,080,000 = Rp 2,970,000

However, considering additional benefits from reduced downtime and extended equipment life (estimated at Rp 9,530,000), total savings reach approximately Rp 319,880,000 for the six-unit intervention period.

Discussion

The findings of this research contribute significantly to both theoretical understanding and practical application of maintenance innovation in heavy-duty diesel engine management. From a theoretical perspective, the results validate the principles of Total Productive Maintenance (TPM) and Reliability-Centered Maintenance (RCM), which emphasize proactive intervention, condition-based monitoring, and optimization of maintenance resources (Dhillon, 2019; Smith et al., 2023).

The 99.2% cost reduction achieved through bracket injector implementation corroborates previous research by Kumar and Chauhan (2021), who reported that preventive maintenance innovations can reduce costs by 60-85% compared to reactive replacement strategies. However, this study extends those findings by demonstrating applicability specifically to fuel injection systems in heavy-duty commercial vehicles operating under severe conditions, which represents a previously underexplored context.

Furthermore, the correlation between early damage detection and extended component lifespan aligns with research by Maleque et al. (2020) on fuel dilution impacts, which demonstrated that early intervention can prevent cascading failures in lubrication systems. The present study provides empirical evidence that visual inspection tools, when properly designed, can effectively identify fuel dilution-related damage before critical failure occurs, thereby validating the diagnostic approach proposed by Park and Lee (2022) for field-level maintenance operations.

The time efficiency improvement (73% reduction in inspection time) has significant implications for fleet management in mining and construction sectors where equipment downtime directly impacts production output. This finding supports the operational efficiency framework proposed by Wong and Tung (2016), which emphasizes that maintenance time reduction should be balanced with inspection quality—a balance successfully achieved in this implementation.

From a practical standpoint, the bracket injector innovation addresses several critical challenges faced by maintenance operations in resource-limited settings. Unlike sophisticated electronic diagnostic equipment that requires specialized training and substantial capital investment (Chen et al., 2021), the bracket injector offers an accessible, affordable, and intuitive solution that can be implemented by technicians with standard mechanical skills. This democratization of diagnostic capability represents an important contribution to maintenance practice in developing economies.

The modular and adaptable design of the bracket injector also suggests potential for broader application across different diesel engine models and manufacturers, although this would require validation through extended testing. Future research should explore the tool's effectiveness on other common heavy-duty platforms such as Hino, Scania, and Volvo trucks operating in similar industrial contexts.

One limitation of this study is the relatively short monitoring period (three months post-implementation), which may not fully capture long-term durability and maintenance benefits. Extended longitudinal studies are needed to assess whether the cost savings and performance improvements persist over full injector service life cycles (typically 10,000-15,000 operating hours). Additionally, while the study demonstrates effectiveness in fuel dilution cases, further research should evaluate the bracket injector's diagnostic capability for other common injector failures such as coking, cavitation erosion, and electrical solenoid malfunctions.

CONCLUSION

The implementation of the injector bracket innovation for fuel spray inspection on the Mercy Axor 2528 unit at PT Antareja Mahada Makmur Site MIFA during April–July 2025 demonstrated substantial benefits, including maintenance cost savings of Rp 319,880,000 previously allocated for new injector assemblies. The bracket allowed earlier damage detection, enabling injectors to be repaired and reused instead of replaced, which enhanced maintenance efficiency, extended injector lifespan, and maintained optimal engine performance through more precise fuel spray patterns. Beyond economic advantages, this innovation contributed to improved technician productivity and overall equipment sustainability within company operations. Future research could focus on applying this injector bracket design to different engine models or integrating sensor-based monitoring systems to further optimize diagnostic accuracy and predictive maintenance capabilities.

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