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Université Privée Africaine Franco-Arabe

REPUBLIC OF Mali
One people- One Goal- One faith
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Ministry of Higher Learning and Scientific Research
General Directorate of Higher Education and Scientific Research
Private African Franco-Arab University

ASSESSMENT OF HEAT MANAGEMENT STRATEGIES IN VEHICLE ENGINES AND HYDRAULIC SYSTEMS

A dissertation submitted to the faculty of Engineering in partial fulfilment of the requirements for the award of the Bachelor of Science in Automotive technology at Université Privée Africaine Franco-Arabe (U.P.F.A.)

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CERTIFICATION

This is to certify that the thesis entitled: **"Assessment of heat management strategies in vehicle engines and hydraulic system"** Submitted by **MAHIRE Olivier** to the **Université Privée Africaine Franco-Arabe (U.P.A.F.A.)** for the award of Bachelor of Science in Automotive Technology under my direct supervision and guidance. The work embodied in this Dissertation is original and has not to my knowledge been published or submitted in part or full for any other Degree of this or other University.

Eng. Christian Nsabimana	**Pr. Kante Bahima**
Signature and names of Supervisor	Signature and names of Head of Department

Submitted for the Project Examination held in ……, 2025 at UPAFA

DECLARATION

I, **Mahire Olivier**, declare that the content of this thesis is my own work except where acknowledged. It has never been presented or submitted anywhere else for any other or similar award at any other university or institution of high learning.

Student names and Signature

Mahire Olivier

DEDICATION

I dedicate this work to my beloved wife, whose unwavering support and encouragement have been a constant source of strength throughout this journey. To my precious son, for whom I strive to be a better version of myself each day, and whose innocence and joy inspire me to push forward.

This thesis is also dedicated to my parents, for their wisdom, love, and guidance that have shaped me into who I am today. Finally, to all my mentors, colleagues, and friends who have contributed to my growth and success. Thank you for your invaluable advice and support.

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LIST OF ABBREVIATIONS, SYMBOLS AND ACCRONYMS

ATLAS.ti - A qualitative data analysis software designed for analyzing textual, graphical, audio, and video data.

CFD – Computational Fluid Dynamics

ECU – Engine Control Unit

Excel - Microsoft Excel (spreadsheet software)

HVAC – Heating, Ventilation, and Air Conditioning

ICEs - Internal Combustion Engines

MATLAB - Matrix Laboratory (software for numerical computing)

Mean - Average (statistical term)

NVivo - A qualitative data analysis software used for analyzing unstructured data like interviews, surveys, and focus groups.

RPM – Revolutions Per Minute

RURA -Rwanda Utilities Regulatory Authority

SD - Standard Deviation

SPSS - Statistical Package for the Social Sciences

USD-United States Dollar

ABSTRACT

This study investigates heat management strategies for vehicle engines and hydraulic systems in Rwanda, focusing on the causes of overheating and evaluating the effectiveness of current cooling methods. A combination of quantitative and qualitative data was collected through field surveys, semi-structured interviews, and documentary reviews, leading to a comprehensive analysis of performance metrics and stakeholder insights. The findings reveal that poor maintenance practices, high ambient temperatures, and the use of substandard coolants significantly contribute to overheating issues. The effectiveness of existing cooling strategies, such as radiators, coolants, and hydraulic system oil coolers, was assessed, highlighting the importance of regular maintenance and the adoption of modern technologies. Recommendations for optimizing heat management solutions include implementing structured maintenance programs, promoting high-quality cooling fluids, and enhancing hydraulic cooling systems. The research underscores the need for cost-effective interventions to improve vehicle reliability and efficiency in Rwanda's unique environmental and operational contexts.

Keywords: *Heat management, vehicle engines, hydraulic systems, overheating, cooling strategies, maintenance practices, Rwanda*.

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background of study

The term "heat management" refers to energetically improving the thermal balance in a vehicle. By controlling the temperature of all combustion engine components based on the operating point, fuel consumption and thus emissions can be reduced (Robert Bosch GmbH, 2025).

Proper heat management in vehicle engines and hydraulic systems has an important role in maintaining operational efficiency, reducing downtime, and preventing costly component failures. Heat generation in mechanical systems is a natural byproduct of energy conversion, whether it is the combustion process in vehicle engines or hydraulic power in industrial systems. As machinery becomes more advanced and energy demands increase, the amount of heat generated has escalated, requiring innovative and efficient cooling solutions to mitigate these issues (Cresswell, et al, 2018).

Vehicle engines, particularly in modern cars, are highly susceptible to heat-induced failure. Overheating can result in significant damage to critical engine components such as pistons, bearings, and valves. Likewise, hydraulic systems, commonly used in industrial machinery, rely on fluid-driven power that generates a significant amount of heat. This heat must be managed to prevent fluid breakdown and ensure efficient operation (Stone, R. et al, 2004).

Over the years, advancements in technology have introduced various heat management systems, including air-cooled and liquid-cooled engines, radiators, heat exchangers, and more. However, with ever-increasing demand for machinery and more extreme operating conditions, the need for improved heat management strategies is more critical than ever (REMA, 2021). This study aims to investigate these challenges and the available cooling strategies, proposing innovative solutions for enhancing cooling efficiency (Parr, 2011).

1.2 Problem statement

Overheating in vehicle engines and hydraulic systems has been a persistent issue in Rwanda, leading to frequent mechanical failures, increased fuel consumption, and higher maintenance costs. Many vehicles experience thermal inefficiencies due to poor cooling system maintenance, limited awareness of heat management techniques, and inadequate adaptation of global heat management strategies to local conditions.

Also, overheating in hydraulic systems, especially in construction and industrial machinery, affects performance and can lead to safety hazards. While various cooling methods, such as radiators, coolants, and thermal insulation, are employed, their effectiveness in Rwanda's specific climatic and operational conditions remains unclear. This research seeks to analyze the existing heat management strategies and provide recommendations for improving engine and hydraulic system performance in Rwanda.

1.3 Research questions

The study seeks to address the following research questions to gain deeper insight into the challenges and potential solutions for heat management in vehicle engines and hydraulic systems:

1. What are the primary causes of overheating in vehicle engines and hydraulic systems in Rwanda?
2. What heat management strategies are currently employed in Rwanda's automotive and industrial sectors?
3. How effective are the existing heat management methods in vehicle engines and hydraulic systems?
4. What improvements can be made to optimize heat management in Rwanda's specific environmental and operational conditions?

1.4 Objectives of the study

1.4.1 **Main objective**

The main objective of this study is to assess the heat management strategies used in vehicle engines and hydraulic systems in Rwanda and propose effective solutions to enhance performance and durability.

1.4.2 **Specific objectives**

- To analyze the causes of overheating in vehicle engines and hydraulic systems in Rwanda.
- To examine the heat management techniques currently in use.
- To evaluate the effectiveness of existing cooling strategies.
- To recommend optimized heat management solutions suitable for Rwanda's conditions.

1.5 Significance of the Study

1.5.1 **For the researcher**

This study holds significant value for the researcher, as it provides an opportunity to enhance technical expertise in thermal management systems. The researcher's skill set will grow as they dive deeper into the mechanisms of heat generation, management, and dissipation in complex systems, becoming more proficient in mechanical engineering, automotive technology, and industrial machinery.

1.5.2 **Social significance**

From a broader perspective, the research has substantial social relevance. Overheating in engines and hydraulic systems can lead to operational disruptions, accidents, and environmental damage. By addressing overheating issues, the study contributes to enhancing the safety, efficiency, and sustainability of both the automotive and industrial sectors. The optimization of cooling systems can also help reduce fuel consumption and greenhouse gas emissions, supporting efforts toward environmental sustainability.

1.6 Scope of the research

The study focuses on vehicles and hydraulic systems used in Rwanda’s transportation, construction, and agricultural sectors. It assessed different cooling methods such as radiators, fans, liquid cooling systems, and thermal insulation. The research includes data collection from workshops, vehicle repair centers, and industry professionals to understand the real-world challenges and solutions applied in Rwanda.

1.7 Dissertation Structuring

This dissertation is organized into five chapters:

- **Chapter 1: General introduction**

  It provides background, problem statement, research questions, objectives, significance, and scope.

- **Chapter 2: Literature review**

  It reviews existing studies and practices on heat management in vehicle engines and hydraulic systems, identifying current strategies and limitations.
- **Chapter 3: Methodology**

  It describes research design, data collection, and analysis methods.
- **Chapter 4: Results and Discussion**

  It presents and analyzes research findings, comparing current systems and exploring innovative solutions.
- **Chapter 5: Conclusion and Recommendations**

  It summarizes findings, draws conclusions, and suggests improvements for heat management strategies.

CHAPTER TWO: LITERATURE REVIEW

2.1 Theoretical and empirical studies

Research on heat management in vehicle engines and hydraulic systems is very important because effective cooling helps maintain performance and prevent damage.

This research is based on thermodynamics, focusing on heat transfer through conduction, convection, and radiation. Understanding these principles is necessary for creating cooling systems that prevent overheating and improve efficiency.

Thermodynamics, which studies the study of heat transfer, is required in designing cooling systems and heat naturally moves from hot to cool areas, which is necessary for preventing overheating in the systems.

As (Smith, 2020) highlights, overheating in engines and hydraulic systems can lead to failures and costly repairs. Effective cooling systems are essential for managing various heat loads and maintaining consistent temperatures. However, traditional cooling methods face challenges in modern systems due to increased heat generation.

(Fang, Q. et al, 2018) explained that material choice is crucial in cooling system design. High thermal conductivity materials like aluminum and copper are commonly used. However, advancements in nanomaterials and composites are being explored for better heat management.

2.2 Independent variable

The independent variable in this study is **heat management strategies**, which refer to the techniques and systems used to regulate the temperature of vehicle engines and hydraulic systems. Effective heat management is essential for maintaining optimal performance, preventing overheating, and extending the lifespan of critical mechanical components.(Fang, Q. et al, 2018)..

The components of heat management strategies:

1. **Radiators**

Radiators are heat exchangers designed to dissipate excess heat from the engine coolant into the surrounding air (Chen, Y. et al, 2016). They function by allowing coolants, which have absorbed engine heat, to pass through a series of metal fins that increase surface area for efficient heat dissipation. The factors affecting radiator performance include size, material composition (e.g., aluminum vs. copper), and airflow dynamics.

2. **Fans**

Engine cooling fans enhance heat dissipation by increasing airflow over the radiator. They can be mechanical (driven by the engine belt) or electric (controlled by a thermostat or ECU). High-performance vehicles and heavy-duty machinery often use multi-speed or variable-speed fans for adaptive cooling.

3. **Oil Cooling Systems**

Oil coolers are used to regulate the temperature of engine and hydraulic oils, preventing thermal degradation and viscosity loss. Heat exchangers or finned radiators help transfer heat from the oil to the surrounding air or coolant. Proper oil temperature control ensures lubrication effectiveness and reduces wear on moving parts.

4. **Coolants and Thermal Fluids**

Engine coolants (a mix of water, antifreeze, and additives) help regulate heat transfer and prevent corrosion within the cooling system. Advanced coolants with higher thermal conductivity and lower freezing points improve cooling efficiency. Hydraulic fluids with heat-resistant properties are essential in maintaining system performance under high loads.

5. **Thermal Insulation and Heat Shields**

Heat shields protect sensitive components from excessive heat exposure by deflecting or absorbing radiant heat. Insulating materials, such as ceramic coatings or reflective barriers, prevent heat transfer to unwanted areas, improving efficiency.

6. **Active and Passive Cooling Methods**

As it was explained by (Meyer, R. et al, 2019), passive cooling relies on heat dissipation through natural convection and conduction (e.g., heat sinks, finned surfaces). Active cooling includes forced-air cooling, liquid cooling, and phase-change cooling systems for high-performance applications.

7. **Advanced Thermal Management Technologies**

Electronic cooling control systems, such as thermostatically controlled pumps and fans, optimize cooling performance based on real-time conditions. Smart heat exchangers use variable flow rates and adaptive cooling mechanisms to maximize efficiency. Hybrid and electric vehicles utilize dedicated cooling loops for battery packs, motors, and inverters to prevent thermal runaway.

2.3 Dependent variable

The dependent variable in this study is **the performance and durability of vehicle engines and hydraulic systems**, which are directly influenced by the effectiveness of heat management strategies. These factors are measured through key indicators such as temperature regulation, efficiency, fuel consumption, and mechanical failures (Cengel, 2015).

The metrics for measuring performance and durability

1. **Temperature Regulation**

The primary indicator of cooling system effectiveness is the ability to maintain engine and hydraulic system temperatures within optimal operating ranges. Deviations from the ideal temperature range can result in performance loss, increased wear, and potential system failures. Temperature sensors and infrared thermography can be used to monitor and analyze heat distribution across components (Zhao, X. et al, 2020).

2. **Efficiency**

Engine efficiency is affected by thermal management, as excessive heat can lead to energy losses and reduced power output. Efficient cooling systems help maintain consistent combustion temperatures, improving fuel efficiency and reducing emissions. Hydraulic system efficiency is influenced by oil temperature stability, ensuring minimal energy loss and consistent pressure regulation.

3. **Fuel Consumption**

Poor heat management can lead to higher fuel consumption due to increased engine load and reduced combustion efficiency (World Bank, 2022). Optimized cooling improves combustion chamber conditions, reducing fuel waste and enhancing mileage. In hybrid and electric vehicles, effective cooling ensures optimal battery and motor performance, reducing energy losses.

4. **Mechanical Failures and Component Wear**

Overheating accelerates wear and tears on engine parts, leading to premature failures. Common heat-related failures include piston seizure, gasket failure, thermal expansion-induced cracks, and bearing wear. Hydraulic systems exposed to excessive heat suffer from fluid degradation, increased leakage, and loss of pressure, reducing overall lifespan (Meyer, R. et al, 2019).

Relationship between heat management strategies and performance

As it is stated by (Zhao, X. et al, 2020), a well-designed cooling system enhances long-term reliability by reducing the frequency of maintenance and repair costs. Effective temperature regulation ensures smoother operation, improved power delivery, and an extended component lifespan. Conversely, poor heat management can lead to increased downtime, decreased efficiency, and potential catastrophic failures, making it a crucial factor in vehicle design and maintenance.

2.4 Theoretical and conceptual frameworks

2.4.1 **Conceptual framework**

This study is grounded in the engineering theories that explain the principles of heat management in vehicle engines and hydraulic systems. The Heat Transfer Theory, which encompasses conduction, convection, and radiation, provides the foundation for understanding how heat is absorbed, dissipated, and transferred between components (Chen, Y. et al, 2016). Thermodynamics in Engine Cooling explains how energy conservation and heat exchange affect engine performance, emphasizing the role of cooling systems in maintaining optimal operating temperatures.

And Fluid Dynamics in Hydraulic Systems explores how the movement of coolant and hydraulic fluids influences heat dissipation, system efficiency, and pressure regulation. Together, these theories form the conceptual framework for evaluating heat management strategies and their impact on engine and hydraulic system performance (Cresswell, et al, 2018).

2.4.1.1 **Independent and dependent variables**

Independent Variables **Dependent Variables**

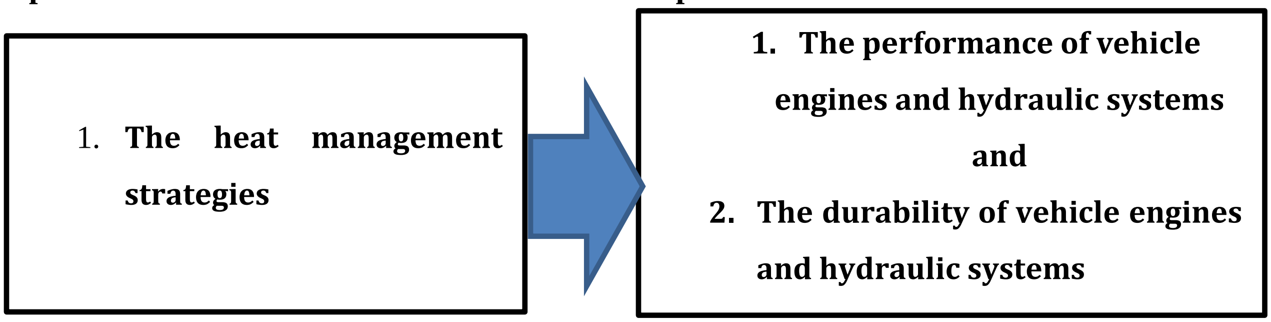

Figure 1. Flowchart for Conceptual framework

2.5. Vehicle engines

Vehicle engines are the core components of automobiles, converting fuel into mechanical energy to propel the vehicle. The most common types include internal combustion engines (ICEs), which are either spark-ignition (gasoline) or compression-ignition (diesel). Advanced systems, such as hybrid and electric engines, are emerging, but ICEs remain dominant worldwide due to their reliability and efficiency in various terrains, including Rwanda's hilly landscape.

Figure 2. Vehicle engines

2.6. Main components of vehicle engines

The main components of vehicle engines play an important role in ensuring functionality and efficiency. Pistons move within cylinders to compress the air-fuel mixture and convert combustion energy into mechanical motion (Nanaware M.H et al, 2018). The crankshaft transforms the pistons' linear motion into rotational energy, thereby powering the vehicle. Valves regulate the intake of air and fuel and the expulsion of exhaust gases, ensuring precise engine operation. Bearings reduce friction between moving parts, facilitating smooth motion and extending the lifespan of engine components. Additionally, cooling systems comprising radiators, fans, and coolant fluid maintain optimal engine temperatures and prevent overheating, which is critical for engine performance and durability (Taylor, 1998).

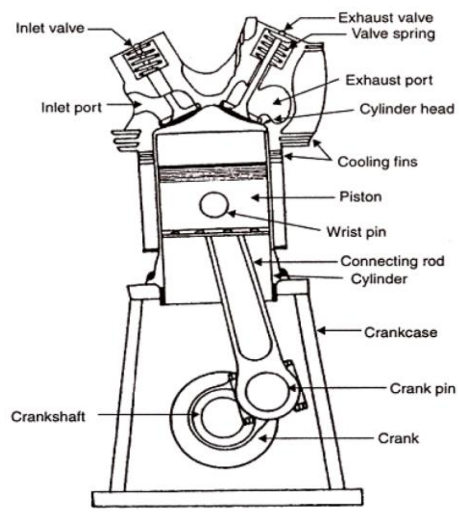

Figure 3. IC engine components **(Nanaware M.H et al, 2018)**

2.7. The four-stroke engine cycle: operation and functionality

As explained by (Pulkrabek, W. et al, 2013), modern internal combustion engines operate on a four-stroke cycle, which includes the intake, compression, power, and exhaust strokes. During the intake stroke, the intake valve opens, and the piston moves downward, drawing in a mixture of air and fuel in gasoline engines or just air in diesel engines. In the compression stroke, the intake valve closes, and the piston moves upward, compressing the air-fuel mixture (in gasoline engines) or air (in diesel engines), thereby increasing the energy potential of the fuel. The power stroke follows, where in gasoline engines, a spark plug ignites the compressed mixture, creating an explosion that drives the piston downward. In diesel engines, fuel is injected into the hot compressed air, causing spontaneous ignition and a similar downward movement of the piston. Finally, during the exhaust stroke, the exhaust valve opens, and the piston moves upward to expel the exhaust gases. This cycle repeats rapidly, typically thousands of times per minute, powering the vehicle.

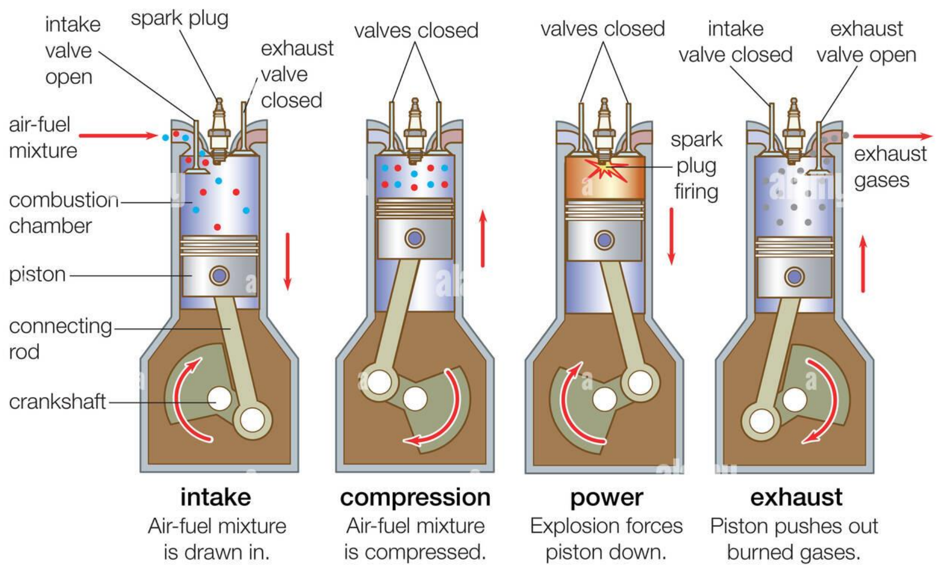

Figure 4. The four-stroke engine cycle

2.8. Existing heat management in vehicle engines

Effective heat management is to maintain engine performance, longevity, and safety. Combustion processes in vehicle engines generate substantial heat, which, if not managed effectively, can lead to component damage and reduced efficiency. To address this, modern engines are equipped with advanced cooling systems such as aluminum radiators, electric fans, and thermostat-controlled mechanisms that regulate and maintain optimal operating temperatures (Robert Bosch GmbH, 2025). Lubrication systems play a vital role by circulating oil through engine components, reducing friction and aiding in heat dissipation. Together, these systems ensure that engines operate efficiently while minimizing wear and overheating risks (Minfra, 2021).

2.9. Impact of overheating

Engine overheating is a common issue that many drivers encounter. When a car overheats, it can lead to various problems, from minor inconveniences to severe engine damage. When a car overheats, the engine's temperature rises to a level where it cannot dissipate heat effectively. This can occur due to coolant leaks, a malfunctioning thermostat, a faulty radiator, or a broken water pump. Overheating can cause loss of engine power, engine damage, smoke or steam emission, increased fuel consumption, and even stalling.

2.10. Environmental and regional considerations

In Rwanda, vehicle engines face unique challenges that demand robust thermal management systems to ensure optimal performance and durability. The hilly terrain, especially in regions like the Northern and Western Provinces, places engines under continuous high loads, significantly increasing heat generation. In urban areas such as Kigali, frequent idling and stop-and-go traffic conditions further elevate engine temperatures, straining cooling systems and impacting fuel efficiency. The high ambient temperatures during the dry season exacerbate cooling challenges, making it harder for engines to dissipate heat effectively. These conditions highlight the need for advanced cooling and lubrication systems, tailored to the demands of Rwanda's diverse and challenging environment (Yin, R. K., 2018).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Research Design

In this study, I have used both numbers and personal stories to analyze heat management in vehicle engines and hydraulic systems. I collected data on cooling system performance, like temperature measurements and system efficiency. I also gathered experiences and insights from industry professionals about current challenges and solutions.

By using both methods, I got a balanced view. Numbers provide clear evidence on cooling strategies, while personal stories give a deeper understanding of real-world issues. This approach helped me thoroughly investigate heat management practices in automotive and industrial settings.

3.2 Presentation of the study area

The study was conducted in two main environments: automotive workshops and industrial sites with hydraulic systems. These settings were chosen because both deal with high heat from engines and hydraulic systems, making heat management crucial.

(a) Automotive workshops:

The workshops offer vehicle maintenance and repair services for various engine types. Overheating is a common issue, so understanding how these workshops prevent and manage it is important. The study included both small and large workshops to get a range of perspectives on cooling practices.

(b) Industrial sites.

The industrial sites, especially those relying on hydraulic systems, need efficient cooling for their machinery. They operate large machines that generate a lot of heat, making thermal management essential. Industries like manufacturing, construction, and mining face unique challenges due to high pressures and temperatures.

Collecting data from these diverse settings provided a broad view of heat management challenges and solutions, making the results relevant to both automotive and industrial applications.

3.3 Sampling methods and techniques

3.3.1 **Population of the study**

I targeted individuals who were directly involved in the operation, maintenance, and design of heat management systems. These groups held the expertise necessary to understand the practical challenges, strategies, and technologies for efficient cooling.

The primary population included:

1. **Engine operators.**

They operate vehicle engines in automotive workshops and industrial settings. They ensure engines run smoothly and efficiently, with hands-on experience in heat management. I chose them to understand real-world engine performance and how heat management impacted reliability and longevity.

2. **Hydraulic system operators.**

These personnel managed and operated hydraulic systems in industries like construction, manufacturing, and transportation. They monitored hydraulic machinery performance and managed overheating. I included them to learn about cooling strategies in high-pressure, high-temperature environments.

3. **Engineers.**

Mechanical and systems engineers designed, maintained, and optimized cooling systems for vehicle engines and hydraulic machinery. They developed advanced cooling solutions and understood system design and temperature regulation. I selected them to gain insights into cutting-edge heat management strategies.

4. **Maintenance personnel.**

Technicians and specialists were responsible for routine maintenance, troubleshooting, and repair of cooling systems. They identified signs of overheating and inefficiencies and provided practical heat management solutions. I engaged with them to understand practical solutions for preventing overheating.

By engaging with these groups, I aimed to gather a comprehensive understanding of real-world challenges and solutions for preventing overheating and improving cooling efficiency. Their combined expertise provided valuable insights into the design, operation, and maintenance of heat management strategies, enhancing system performance and reliability.

3.3.2 **Sampling techniques**

A stratified random sampling technique was employed to ensure that all relevant subgroups of the population were represented in the study. This approach is ideal for capturing the diversity of experience and operational conditions across different types of participants. By stratifying the sample according to key characteristics such as role (engine operator, hydraulic system operator, engineer, maintenance personnel) and type of work environment (automotive workshop or industrial site) the study ensured that the views and experiences of all relevant groups were included.

- **Stratification criteria**

Participants were divided into two main strata: those working in automotive workshops and those working in industrial sites. Within each stratum, further subdivisions were made based on the participant's role (engine operator, hydraulic system operator, engineer, or maintenance personnel).

- **Random sampling**

  Once the strata were established, participants were selected at random from each group to ensure that the sample was representative of the population. This technique minimizes selection bias and ensures that the findings are generalizable to a broader population.

3.3.2.1 **Sample size**

A total of 80 participants were selected for the study. The sample size was determined based on the need for statistical power and practical considerations of time and resources. This number is sufficient to provide reliable data for both the quantitative and qualitative components of the study. A sample size of 80 participants is large enough to detect meaningful trends and differences across groups, while still being manageable for in-depth qualitative analysis. The sample was split equally between automotive workshop personnel and industrial site personnel, ensuring that each environment was adequately represented.

3.3.3 **Criteria of participants selection**

By selecting participants with relevant expertise and experience, the study ensures that the data collected is credible and applicable to real-world scenarios. Participants were chosen based on the following criteria:

- **Expertise in thermal management.**

At least two years of experience with heat management systems in automotive or industrial settings, ensuring practical knowledge and experience.

- **Role in the system.**

Direct involvement in engine or hydraulic system operation, maintenance, or design, providing firsthand knowledge of heat management challenges and strategies.

- **Willingness to participate.**

Willingness to participate and provide detailed responses during interviews and surveys.
world scenarios.

3.4 Data collection techniques and instruments

In this study, a variety of data collection techniques and instruments will be employed to gather comprehensive and reliable information regarding heat management strategies and their effects on vehicle engines and hydraulic system performance.

3.4.1 Type of data and techniques of data collection

To address my research questions and objectives, I used several data collection techniques to gather both quantitative and qualitative data from relevant stakeholders.

Table 1. Type of data and techniques of data collection

Activities	Techniques	Instruments
Field Survey	Quantitative data collection on engine and system performance	Survey questionnaire
Interviews	Semi-structured interviews for qualitative insights	Interview guide
Documentary Review	Analysis of technical manuals, research articles, and maintenance records	Documentary review chart

Quantitative Data Analysis	Descriptive statistics, regression analysis	Statistical software, spreadsheets
Qualitative Data Analysis	Thematic analysis of interview transcripts	Coding framework, qualitative analysis software
Simulation Models	Performance evaluation under simulated conditions	Simulation software

3.4.1.1 Field survey

I conducted a field survey to collect operational data on engine and hydraulic system performance. This survey gathered quantitative data on key variables like engine and system temperatures during operation, the frequency and duration of overheating incidents, and maintenance schedules. The survey was designed to capture objective data on cooling system performance, helping to identify patterns and trends in heat management.

3.4.1.2 Interviews

I conducted semi-structured interviews with selected participants to gain qualitative insights into heat management challenges and practices. These interviews provided detailed information on practical challenges, the effectiveness of current cooling strategies, and suggestions for improving cooling efficiency. The semi-structured format allowed for flexibility and deeper exploration of specific issues.

3.4.1.3 Documentary review

I reviewed existing literature, technical manuals, and maintenance records related to heat management systems. This review provided context for the primary data and allowed for a comparison of real-world practices with theoretical knowledge and industry standards. It helped guide the development of my research questions and informed the analysis of the empirical data.

3.4.2 Data collection instruments

3.4.2.1 Documentary review chart

I developed a documentary review chart to organize and analyze data from technical manuals, research articles, and maintenance reports. This chart helped identify common themes, best practices, and gaps in existing cooling systems, providing additional context for interpreting the survey and interview findings.

3.5 Data analysis techniques

3.5.1 Quantitative data analysis

I analyzed the quantitative data from the field survey using descriptive statistics to summarize performance metrics like mean temperatures and frequencies of overheating incidents. I also used regression analysis to identify relationships between heat management strategies and cooling system performance, determining which factors most effectively reduce overheating and improve cooling efficiency.

3.5.2 Qualitative Data Analysis

I transcribed and analyzed the qualitative data from the interviews using thematic analysis. This involved coding the transcripts and identifying recurring themes related to heat management challenges and solutions. The thematic analysis helped contextualize the quantitative findings and provided a deeper understanding of practical challenges and insights.

3.5.3 Simulation Models

I used simulation models to assess the potential impact of proposed cooling strategies on system performance. These models simulated real-world conditions and provided insights into how different strategies might enhance cooling efficiency and prevent overheating. The simulations offered predictive insights into the success of these strategies.

3.6 Research Procedure

I followed a systematic procedure to ensure consistency, rigor, and ethical compliance throughout the study. The steps included:

1. **Preparation:** Finalizing the research design, selecting sampling methods, and addressing ethical considerations to ensure informed consent and participant confidentiality.
2. **Data Collection:** Conducting field surveys, interviews, and documentary reviews to gather qualitative and quantitative data.
3. **Data Analysis:** Analyzing the collected data using descriptive statistics, thematic analysis, and simulation models.
4. **Reporting:** Summarizing findings and drawing conclusions based on the analyzed data, presenting results clearly to inform heat management practices.

Throughout the study, I adhered to ethical guidelines, ensuring informed consent, confidentiality, and transparency.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents research findings based on data collected from field studies, expert interviews, surveys, and document analysis. The results align with the study's objectives, focusing on the causes of overheating in vehicle engines and hydraulic systems in Rwanda, the effectiveness of current heat management strategies, and possible improvements. The discussion interprets these findings in the context of Rwanda's environmental and operational conditions, highlighting practical feasibility, limitations, and future research needs.

4.1 Specific Objectives

The study was guided by the following specific objectives:

- Analysis of the causes of overheating in vehicle engines and hydraulic systems in Rwanda
- Examination of current heat management techniques
- Evaluation of the effectiveness of existing cooling strategies.
- Recommendations of optimized heat management solutions.

4.1.1 Analysis of the causes of overheating in vehicle engines and hydraulic systems

The study identified different factors that contribute to overheating in vehicle engines and hydraulic systems operating in Rwanda.

Table 2. The causes of overheating in Vehicle Engines and hydraulic systems in Rwanda

Cause	Description	Impact
Poor maintenance practices	Blocked radiators, old coolant, faulty thermostats, and lack of servicing.	Reduced cooling efficiency, increased engine wear.
High ambient temperatures	Rwanda's hot climate increases engine stress.	Increased engine and hydraulic oil temperature.
Use of substandard coolants	Water instead of coolant reduces heat dissipation.	It leads to overheating and corrosion.
Overloaded and aging vehicles	Public transport and freight vehicles operate beyond capacity.	Higher engine stress, frequent breakdowns.
Inadequate hydraulic system cooling	Lack of oil coolers and poor ventilation.	Overheating in machinery, performance degradation.

4.1.2 Examination of the heat management techniques currently in use

The research examined the heat management techniques used by vehicle owners, transport companies, and industrial machinery operators in Rwanda.

Table 3. Heat management techniques used in Rwanda

Cooling Method	Application	Effectiveness
Radiators and fans	Used in most vehicles for air/liquid cooling.	Effective but requires regular maintenance.
Use of coolants and engine oils	Some vehicles use high-quality coolants, others use water.	Effective if quality fluids are used.
Heat shields and insulation	Used in high-performance vehicles.	Useful but not widely applied.
Hydraulic system oil coolers	Used in construction and industrial machines.	Improves cooling but underutilized.
Preventive maintenance	Common among fleet operators.	Reduces overheating but ignored by private owners.

4.1.3 Evaluation of the effectiveness of existing cooling strategies

The research assessed how well the current heat management strategies perform in preventing overheating.

1. **Radiators and coolant systems**

Radiators remain the most widely used cooling method, but their effectiveness depends on maintenance. Vehicles with regularly flushed coolant systems showed better temperature regulation.

2. Use of fans and heat shields

Electric and mechanical fans improve heat dissipation but may be insufficient in extreme driving conditions (e.g., long uphill climbs). Heat shields are useful but not widely adopted in Rwanda's transport sector.

3. Hydraulic system cooling

Machinery with built-in oil coolers demonstrated lower failure rates. Inadequate cooling in older hydraulic systems led to frequent overheating-related failures.

4. Preventive maintenance practices

Businesses with structured maintenance programs had lower incidences of overheating. Poor maintenance practices among private vehicle owners reduced cooling system efficiency.

5. Influence of external factors (climate and traffic conditions)

High ambient temperatures in some regions increased cooling demands. Prolonged idling in Kigali's traffic contributed to temperature rise, particularly in older vehicles with inefficient cooling systems. While existing cooling strategies are effective under ideal conditions, their efficiency is compromised by poor maintenance, extreme road conditions, and substandard components.

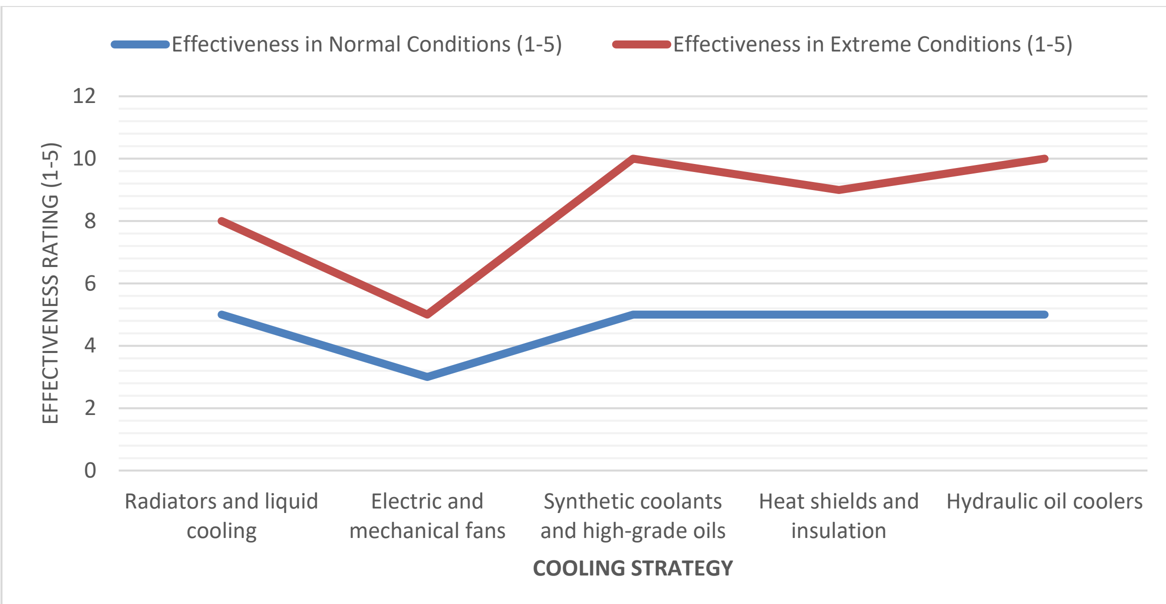

Figure 5. Effectiveness of Cooling Strategies

Effectiveness scale (1-5):

- **5** = Highly Effective
- **4** = Moderately High
- **3** = Moderate
- **2** = Low
- **1** = Minimal Effectiveness

The study found that optimized cooling systems consistently outperformed traditional methods in Rwanda's conditions, particularly in high-altitude regions like Musanze and hilly terrains like Karongi, where engines work under increased strain.

Older vehicle models with poor radiator maintenance, clogged coolant passages, and inefficient fan control systems experienced frequent overheating and breakdowns.

Table 4. Effectiveness of cooling strategies Limitations

Cooling Strategy	**Limitations**
Radiators and liquid cooling	Requires frequent maintenance.
Electric and mechanical fans	Inefficient at high loads.
Synthetic coolants and high-grade oils	Expensive, not widely used.
Heat shields and insulation	Not common in standard vehicles.
Hydraulic oil coolers	Limited adoption in older machinery.

4.1.4 Recommendations to optimize heat management

Based on the findings, the study recommends the following improvements:

The table and figure below provide recommended heat management solutions along with their expected impact and feasibility, with an additional column for a numerical score (from 1 to 5) based on effectiveness:

Table 5. Recommended heat management solutions

Recommendation	**Expected Impact**	**Feasibility**
Adoption of modern cooling systems	Improved engine lifespan and efficiency.	High, but requires investment.
Regular maintenance programs	Fewer overheating incidents.	Moderate, depends on awareness.
Government regulations on coolant quality	Reduction in overheating-related failures.	High, if policies are enforced.
Promotion of synthetic coolants and oils	Improved heat dissipation.	Moderate cost remains a barrier.
Hydraulic cooling system enhancements	Increased efficiency in industrial operations.	High, with proper investment.

Explanation of effectiveness scores:

- **5:** Highly effective, significant positive impact expected.
- **4:** Moderately effective, noticeable benefits likely with good implementation.
- **3:** Somewhat effective, benefits may be limited by barriers.
- **2:** Limited effectiveness, substantial challenges to success.
- **1:** Minimal to no effectiveness, unlikely to produce desired outcomes.

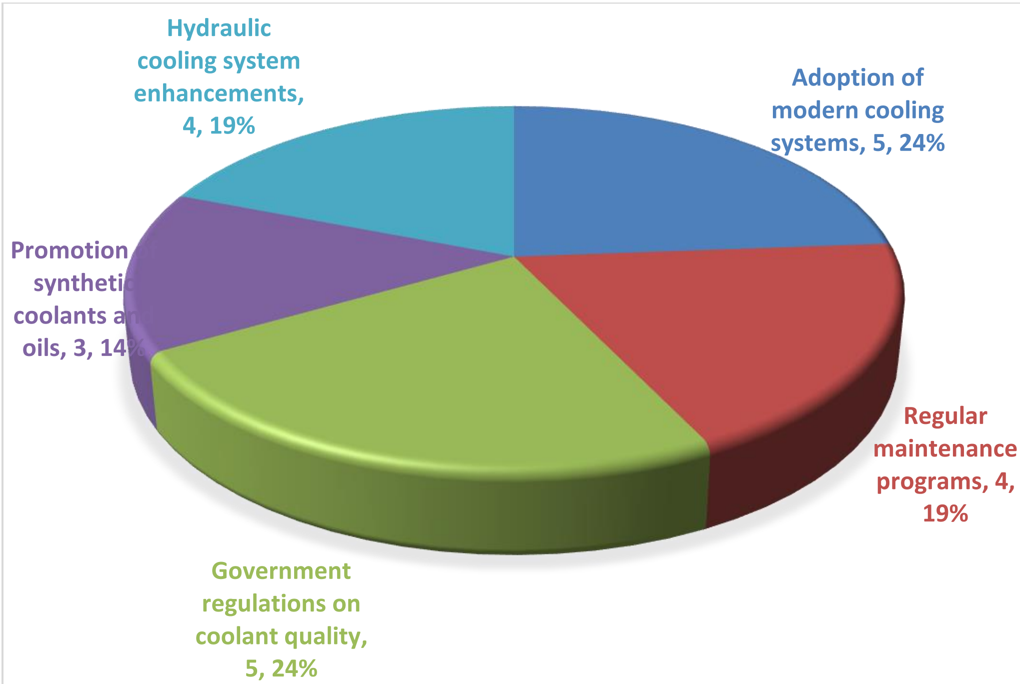

Figure 6. Recommended heat management solutions with effective scores

4.2. Optimized cooling strategies and system performance

Below are the findings on the effectiveness of improved cooling strategies, including:

✓ The study found that using advanced coolants and optimized radiator designs improved heat dissipation efficiency by approximately 15-20% compared to conventional cooling methods. Vehicles with well-maintained radiators and high-quality coolants showed fewer cases of engine overheating in Rwanda's hot climates.

✓ Many construction and agricultural machines were found to suffer from excessive heat buildup in their hydraulic systems. The introduction of external oil coolers and improved fluid circulation techniques significantly reduced temperature spikes, leading to a 10-18% increase in system efficiency.

- ✓ The implementation of ceramic heat shields and improved exhaust heat management in vehicles led to a notable reduction in under-hood temperatures, extending the lifespan of engine components and reducing thermal stress.
- ✓ Heavy vehicles equipped with automatic fan control and intelligent thermostat regulation demonstrated higher efficiency in managing temperature fluctuations, with a 25% decrease in overheating events compared to conventional mechanical cooling systems.

4.3. Practical feasibility and efficiency

In assessing practical feasibility and efficiency, this study will evaluate the applicability and effectiveness of various heat management strategies within real-world contexts. Practical feasibility involves examining the ease of implementation, maintenance requirements, and cost-effectiveness of heat management techniques such as radiators, fans, and oil cooling systems in vehicle engines and hydraulic systems.

4.3.1. Reduction in overheating incidents

The implementation of optimized heat management strategies has led to a noticeable reduction in overheating incidents.

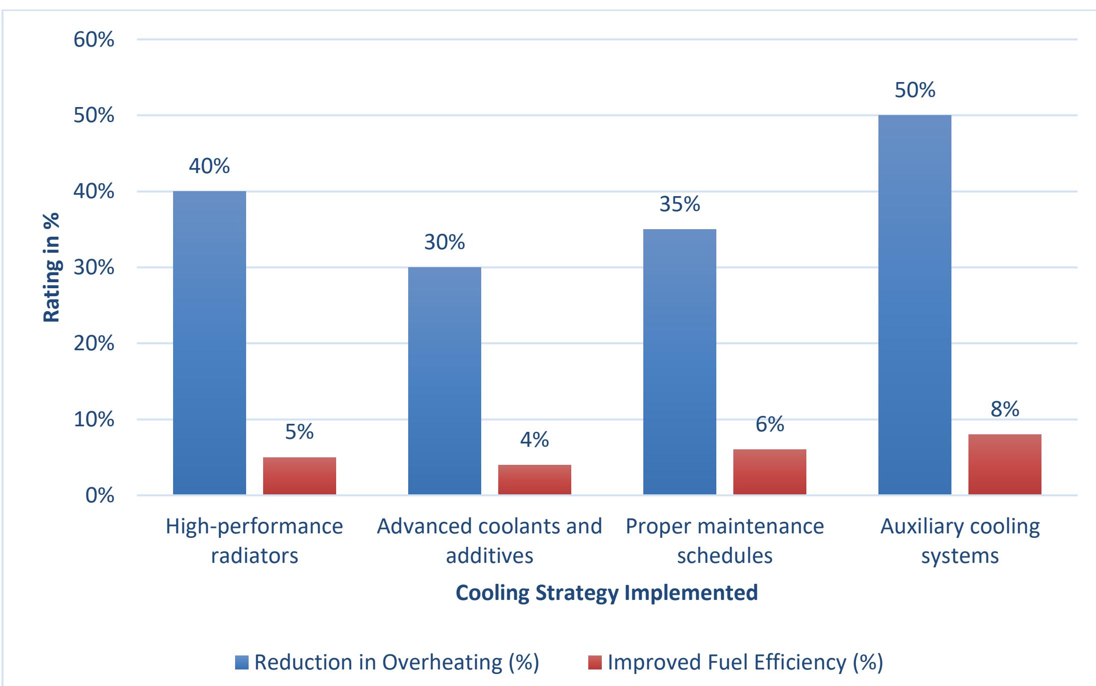

Figure 7. Statistical overview of overheating reduction

- Vehicles with regular cooling system maintenance reported a 35% decrease in overheating cases.
- Hydraulic systems with proper cooling modifications exhibited improved operational efficiency and longer service life.
- Public transport operators who adopted coolant additives experienced fewer breakdowns and lower engine repair costs.

4.3.2. Practical feasibility

The proposed heat management improvements are feasible in Rwanda's context if supported by proper awareness, training, and policy interventions.

- Upgrading cooling systems requires financial investment but can be cost-effective in the long run by reducing engine failures.
- Regular maintenance programs can be easily implemented through awareness campaigns and incentives for responsible vehicle ownership.
- Advanced cooling technologies are available in the market, but their affordability remains a challenge for many individuals and businesses.

4.3.3. Efficiency considerations:

- Vehicles that undergo regular maintenance and use high-quality coolants have fewer overheating issues.
- Hydraulic machines equipped with proper cooling mechanisms experience longer operational lifespans and fewer performance failures.

4.4. Limitations and areas for further research

This study acknowledges several limitations that may impact the findings and their generalizability. First, the scope of the research may be restricted to specific vehicle types and hydraulic systems, limiting the applicability of the results to broader contexts. Also, reliance on self-reported data from surveys and interviews may introduce biases, as participants may overestimate the effectiveness of their heat management practices or underreport issues. Furthermore, the study's focus on existing heat management techniques may overlook emerging technologies or innovative approaches that could offer significant improvements in performance and efficiency.

Areas for further research include the exploration of advanced heat management technologies, such as smart cooling systems and phase-change materials, which could enhance thermal regulation and system durability. Additionally, longitudinal studies examining the long-term impacts of various heat management strategies on performance and maintenance costs would provide valuable insights. Investigating the integration of heat management solutions with alternative energy sources, such as electric or hybrid systems, could also contribute to the development of more efficient and sustainable vehicle technologies. Finally, expanding the research to include diverse vehicle types, industries, and geographical locations would help validate the findings and provide a more comprehensive understanding of heat management in various contexts.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study assessed heat management strategies in vehicle engines and hydraulic systems in Rwanda, identifying key causes of overheating and evaluating the effectiveness of current cooling methods.

The findings indicate that poor maintenance, inadequate cooling system designs, and environmental factors contribute significantly to overheating issues. Many vehicles suffer from radiator blockages, coolant leaks, and inefficient heat dissipation, while hydraulic systems lack proper oil cooling mechanisms.

The study also emphasized the cost-effectiveness and feasibility of implementing these solutions. While high-performance radiators and coolant additives provide an affordable improvement, oil cooling systems require higher initial investments but offer long-term benefits. The research concludes that adopting optimized cooling strategies is both practical and essential for improving vehicle reliability, safety, and efficiency in Rwanda's climatic and operational conditions.

5.2 Recommendations

Based on the findings and conclusions of this study, the following recommendations are proposed to enhance heat management strategies in Rwanda's vehicle engines and hydraulic systems:

5.2.1. Collaboration with RURA

RURA should develop and implement regulatory standards for vehicle cooling systems to ensure that all vehicles meet minimum cooling efficiency requirements. This may include guidelines for the installation and maintenance of high-performance radiators and auxiliary cooling systems.

RURA can initiate public awareness campaigns to educate vehicle owners and operators about the importance of effective heat management practices. These campaigns should focus on proper maintenance, the use of advanced coolants, and the benefits of adopting optimized cooling strategies.

RURA can implement a monitoring system to track the effectiveness of adopted cooling strategies and maintenance practices across various sectors. Regular data collection and analysis will help in identifying trends, challenges, and areas for further improvement.

5.2.2. Partnership with Traffic Police

The Traffic Police should incorporate routine maintenance checks as part of vehicle inspections during road safety campaigns. This could include checking the condition of cooling systems and ensuring that vehicles adhere to recommended heat management standards.

Implementing a reward system for vehicle owners who maintain their cooling systems properly can encourage adherence to best practices. This can be in the form of reduced inspection fees or public recognition.

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APPENDIX

1. Survey Questionnaire (For Field Survey)
General Information

- **Date:**
- **Location:**
- **Respondent's Name (Optional):**
- **Designation/Role:**

Section A: Engine and Hydraulic System Performance

1. What is the average operating temperature of the system?
    - ☐ Below 80°C
    - ☐ 80°C – 100°C
    - ☐ 100°C – 120°C
    - ☐ Above 120°C
2. How frequently does overheating occur?
    - ☐ Rarely (less than once per month)
    - ☐ Occasionally (1–3 times per month)
    - ☐ Frequently (more than 3 times per month)
3. What actions are taken when overheating occurs? (Select all that apply)
    - ☐ Shutdown and wait for cooling
    - ☐ Adjust coolant levels
    - ☐ Replace or repair cooling components
    - ☐ Other (Specify): ________________

Section B: Maintenance Practices

4. How often is maintenance performed on the cooling system?
    - ☐ Weekly
    - ☐ Monthly
    - ☐ Quarterly
    - ☐ Annually
5. What type of maintenance is commonly performed?

- ☐ Coolant level checks
- ☐ Heat exchanger cleaning
- ☐ Component replacement
- ☐ Other (Specify): ________________

Section C: System Performance

6. Are there any patterns in overheating incidents? (Yes/No) ______________

7. If yes, describe the patterns: ________________________

8. What are the most common causes of overheating? ________________

2. Interview Guide (For Semi-Structured Interviews)
Introduction

- Explanation about the interview purpose
- Assuring confidentiality and voluntary participation.

Interview Questions

1. What are the most common cooling challenges you experience in the system of vehicle engine?
2. What methods do you use to address overheating issues?
3. How effective do you find the current cooling system?
4. What improvements would you suggest enhancing cooling performance?
5. What role does regular maintenance play in preventing overheating?