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Development of an eco-efficient EcoFlow portable fluid management system (EcoFlow-PFMS) for environmentally responsible automotive maintenance

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ABSTRACT

The increasing demand for environmentally responsible automotive maintenance has highlighted the need for innovative technologies that reduce fluid spillage, improve resource efficiency, and promote the safe handling and recovery of hazardous automotive fluids. This study developed and evaluated the Eco-Efficient EcoFlow Portable Fluid Management System (EcoFlow-PFMS), a compact, rechargeable, multifunctional device designed to integrate automotive fluid filling, transfer, and suction into a single portable unit for environmentally sustainable maintenance operations. A developmental research design was employed involving the conceptual design, fabrication, assembly, and functional testing of the prototype. The developed system was evaluated by 50 respondents, comprising 30 automotive technicians, 10 automotive shop owners, and 10 customers, using a structured five-point Likert-scale questionnaire, while descriptive statistics were used to analyze user evaluations. Operational performance was assessed by measuring the average transfer time of one liter of automotive fluid under three operating modes. The EcoFlow-PFMS obtained an overall acceptability rating of 4.94 (Very Highly Acceptable), with the highest ratings recorded for ease of transport (4.99) and ease of operation and portability (4.98). Performance testing demonstrated average transfer times of 31.84 s/L for Filling 1, 33.18 s/L for Filling 2, and 52.40 s/L for the Suction function, indicating reliable and consistent performance across fluids with different viscosity levels. The findings demonstrate that the EcoFlow-PFMS is an effective and eco-efficient engineering innovation that improves automotive maintenance efficiency, minimizes fluid waste and environmental contamination, and supports cleaner production and sustainable automotive servicing, with strong potential for adoption in automotive workshops, mobile service operations, and roadside maintenance.

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INTRODUCTION

The continuous expansion of the global automotive industry has enhanced economic growth and transportation efficiency but has also increased environmental challenges associated with the handling, transfer, and disposal of automotive fluids such as engine oil, transmission fluid, brake fluid, and lubricants. These fluids are considered hazardous wastes because improper handling can contaminate soil, surface water, and groundwater, posing significant risks to ecosystems and public health (United Nations Environment Programme [UNEP], 2023; United States Environmental Protection Agency [USEPA], 2023). The increasing volume of waste oil generated through routine vehicle maintenance has intensified the need for cleaner and more sustainable maintenance technologies that minimize pollution, improve resource efficiency, and support environmentally responsible practices (International Energy Agency [IEA], 2023). Consequently, the development of eco-efficient engineering solutions for automotive servicing has become increasingly important within the broader context of sustainable industrial development.

Automotive maintenance operations, including fluid filling, replacement, transfer, and extraction, are essential for maintaining vehicle reliability, operational efficiency, and safety. However, these activities commonly rely on multiple single-purpose devices that are often bulky, dependent on external electrical power, and susceptible to fluid leakage during operation. Such limitations increase maintenance time, equipment costs, and the likelihood of fluid spillage, resulting in unnecessary waste of petroleum-based products and increased environmental contamination (European Environment Agency [EEA], 2022). These challenges are particularly evident in developing countries such as the Philippines, where many automotive workshops, roadside mechanics, and service providers have limited access to specialized equipment, especially in rural and geographically isolated areas. The absence of portable and multifunctional fluid management systems restricts operational efficiency while increasing occupational and environmental risks associated with improper fluid handling (World Health Organization [WHO], 2022).

The transition toward cleaner production and circular economy practices has encouraged the development of engineering technologies that reduce waste generation, conserve resources, and prevent pollution at its source. Green engineering emphasizes the design of systems that minimize hazardous waste while improving environmental and operational performance (Anastas and Zimmerman, 2018). Likewise, sustainable product development promotes multifunctionality, material efficiency, durability, and energy conservation throughout a product's life cycle (Ashby, 2022). Integrating multiple automotive fluid management functions into a single portable system can reduce equipment redundancy, lower material consumption, improve workplace efficiency, and decrease the environmental footprint associated with manufacturing, transportation, and maintenance operations (United Nations Industrial Development Organization [UNIDO], 2022). These objectives are also aligned with the United Nations Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), which promote sustainable industrial technologies and environmentally responsible resource management (United Nations, 2015).

Despite advances in automotive servicing technologies, a significant gap remains in the availability of compact, portable, battery-powered systems capable of performing multiple fluid management functions within a single device. Existing equipment generally performs only one operation, such as fluid filling or extraction, requiring technicians to transport several machines during routine servicing and roadside maintenance. This limitation reduces operational flexibility, increases equipment handling, and elevates the risk of fluid leakage and environmental contamination. Addressing this gap requires an integrated engineering solution that combines portability, operational efficiency, ergonomic design,

and environmentally responsible fluid handling to improve both maintenance performance and sustainability.

In response to these challenges, this study developed the Eco-Efficient EcoFlow Portable Fluid Management System (EcoFlow-PFMS), a compact rechargeable device that integrates three essential automotive fluid management functions: Filling 1 (F1) for medium-viscosity fluids, Filling 2 (F2) for high-viscosity fluids and Suction (S) for extracting low-viscosity fluids. The system was designed to minimize fluid spillage, improve the recovery and controlled transfer of automotive fluids, enhance workplace safety, and reduce dependence on multiple conventional maintenance tools. Through the application of biosystems engineering, green engineering, and sustainable product design principles, the EcoFlow-PFMS aims to provide an eco-efficient, portable, and practical solution for automotive workshops, mobile service operations, and roadside maintenance. Specifically, this study sought to design and fabricate the EcoFlow-PFMS, evaluate its functionality, operational efficiency, portability, ease of use, safety, and overall acceptability, and identify opportunities for further improvement and wider application in environmentally responsible automotive maintenance.

MATERIALS AND METHODS

Research design

This study employed a developmental research design to develop and evaluate the Eco-Efficient EcoFlow Portable Fluid Management System (EcoFlow-PFMS), a portable multifunctional device intended for automotive fluid filling, transfer, and extraction. Developmental research is widely used in engineering and technology studies to design, fabricate, refine, and validate innovative products through iterative prototype development and evaluation (Creswell and Creswell, 2023).

The research was conducted in two sequential phases. The first phase focused on product development, which included problem identification, needs assessment, conceptual design, component selection, prototype fabrication, assembly, and functional verification. The second phase involved performance testing and user evaluation to determine the operational efficiency, usability, portability, safety, and overall acceptability of the developed system. This two-stage approach enabled both technical validation and end-user assessment before considering broader application of the technology.

Study participants and sampling

A purposive sampling strategy was adopted to recruit respondents possessing practical knowledge and experience in automotive maintenance. This non-probability sampling technique was considered appropriate because the study required evaluations from individuals who routinely perform or supervise automotive servicing operations.

Fifty respondents participated in the product evaluation, comprising:

1. 30 automotive technicians,
2. 10 owners or managers of automotive repair and service centers, and
3. 10 customers with regular experience in automotive maintenance services.

These participant groups provided complementary perspectives regarding the technical performance, operational practicality, and user acceptability of the developed system.

To further examine the commercialization potential of the prototype, an additional market assessment involving 30 automotive technicians was conducted to obtain information regarding perceived industry demand, market feasibility, and potential adoption within automotive service establishments.

Description of the EcoFlow portable fluid management system

The EcoFlow Portable Fluid Management System (EcoFlow-PFMS) is a compact rechargeable fluid management device designed to integrate three automotive maintenance operations within a single portable platform:

1. Filling 1 (F1): medium-viscosity automotive fluids;
2. Filling 2 (F2): high-viscosity automotive fluids; and
3. Suction (S): extraction of low-viscosity fluids.

The prototype measures approximately 22 cm × 27 cm and weighs approximately 6 kg, making it suitable for workshop use, mobile servicing, field maintenance, and roadside repair operations.

The system operates using a rechargeable 12-V battery and therefore does not require continuous connection to an external electrical power source. User controls include independent function switches, battery status indicators, and an emergency stop switch to improve operational safety. High-pressure hoses and corrosion-resistant fittings facilitate controlled fluid transfer while minimizing leakage and contamination. The enclosure was designed to withstand routine workshop conditions while maintaining portability and ease of handling.

Materials used in prototype fabrication

Prototype fabrication utilized commercially available mechanical, structural, and electrical components selected according to durability, compatibility, safety, and operational reliability.

The principal components included:

1. 12-V rechargeable battery and charging system;
2. Three independent 12-V DC pumps;
3. Function selector switches;
4. Main power switch;
5. Indicator lights;
6. Electrical wiring;
7. High-pressure rubber hoses;
8. Stainless-steel connectors and fittings;
9. Galvanized iron housing;
10. Aluminum welding materials;
11. Fastening bolts and mounting hardware; and
12. Protective acrylic coating.

Material selection emphasized structural integrity, corrosion resistance, electrical safety, portability, and long-term operational performance under typical automotive maintenance conditions.

Prototype development procedure

Development of the EcoFlow-PFMS followed a systematic engineering design process consisting of:

1. Identification of operational problems;
2. Determination of user requirements;
3. Conceptual system design;
4. Component selection;
5. Fabrication and assembly;
6. Prototype integration;
7. Functional verification;
8. Engineering performance testing;
9. User evaluation; and
10. Design refinement.

During fabrication, individual electrical and mechanical components were inspected for compatibility before system integration. After assembly, the prototype underwent repeated functional testing to verify switching among the three operating modes, battery performance, pumping efficiency, and leak-free operation. Feedback obtained during user evaluation was incorporated into minor design refinements to improve usability and operational reliability.

Performance testing

Technical performance evaluation focused on verifying the operational capability of the developed prototype under representative automotive servicing conditions.

The following performance parameters were assessed:

1. Fluid transfer time for Filling 1;
2. Fluid transfer time for Filling 2;
3. Suction performance;
4. Battery endurance;
5. Operational stability;
6. Leakage resistance;
7. Portability; and
8. Functionality of safety components.

Each fluid transfer operation was conducted in five consecutive trials using one-liter volumes to evaluate consistency of pumping performance. Mean transfer time was calculated for each operating mode. Leak

inspection, switching performance, battery operation, and emergency stop functionality were verified throughout testing.

The prototype was also operated under normal workshop environmental conditions to assess reliability during routine use.

Instrumentation

User acceptability was assessed using a structured evaluation questionnaire developed from the study objectives and major engineering performance indicators. The instrument evaluated:

1. Operational efficiency;
2. Functionality;
3. Ease of operation;
4. Portability;
5. Ergonomics;
6. Safety;
7. Durability; and
8. Overall design.

Responses were measured using a five-point Likert scale, where 5 represented the highest level of agreement and 1 represented the lowest level. The questionnaire was designed to provide a standardized assessment of user perceptions regarding the developed technology, consistent with principles of human-centered product evaluation (ISO 9241-210).

Data collection procedure

Following successful prototype testing, respondents were provided with a demonstration of the EcoFlow-PFMS and were allowed to observe or operate the system under controlled conditions. After the evaluation session, respondents completed the structured questionnaire independently.

All completed questionnaires were reviewed for completeness prior to data encoding and statistical analysis.

Statistical analysis

Descriptive statistical methods were employed to summarize the evaluation results.

The following statistics were computed:

1. Frequency;
2. Percentage;
3. Weighted mean; and
4. Standard deviation.

Weighted mean values were used to determine the level of acceptability for each evaluation criterion and for the overall performance of the EcoFlow-PFMS. Descriptive statistics were considered appropriate because the primary objective of the evaluation was to describe respondent perceptions of the developed prototype rather than to test inferential hypotheses.

RESULTS AND DISCUSSION

Assessment of the eco-efficient EcoFlow portable fluid management system (F2S machine) based on its operational attributes

The Eco-Efficient EcoFlow Portable Fluid Management System (F2S Machine) was evaluated by 50 respondents, comprising 30 automotive technicians, 10 auto-care service center owners, and 10 customers, to determine its acceptability in terms of operational performance, ease of use, portability, safety, and overall design. As presented in Table 1, the developed prototype obtained a grand mean of 4.94, corresponding to the descriptive rating of Very Highly Acceptable. The consistently high ratings across all respondent groups indicate that the developed system effectively satisfied the operational requirements of both automotive service providers and end-users.

Among the evaluated attributes, ease of transport received the highest mean score (M = 4.99), followed by ease of operation (M = 4.98) and portability for workshop and field applications (M = 4.98). These findings indicate that the compact structure, rechargeable battery-powered operation, and multifunctional configuration of the EcoFlow F2S Machine successfully enhanced user convenience and operational flexibility. The integration of Filling 1 (F1), Filling 2 (F2), and Suction (S) into a single portable unit reduces the need for multiple independent devices, thereby simplifying maintenance procedures and improving workflow

efficiency. This observation supports the principles of sustainable product design, which emphasize multifunctionality, durability, efficient resource utilization, and reduced material consumption through integrated engineering solutions (Ashby, 2022). Likewise, green engineering advocates the development of technologies that prevent pollution, improve resource efficiency, and reduce environmental impacts throughout the product life cycle (Anastas and Zimmerman, 2018).

The attribute receiving the lowest mean score, although still interpreted as Very Highly Acceptable, was the suitability of the machine's size and weight (M = 4.86). While respondents considered the prototype sufficiently portable for routine automotive servicing, this result suggests opportunities for future refinement through lightweight structural materials, optimized component arrangement, or further miniaturization. Such improvements could enhance operator comfort without compromising structural integrity or operational reliability.

High ratings for operational safety (M = 4.93) and overall design and layout (M = 4.94) further demonstrate that respondents considered the machine easy to understand and operate. The incorporation of clearly identified controls, rechargeable battery operation, and integrated functions contributes to a user-friendly maintenance system that minimizes unnecessary equipment handling and reduces the potential for operational errors. Similar findings have been reported in engineering design studies, where ergonomic and intuitive equipment layouts improve operational efficiency, user satisfaction, and workplace safety (ISO 9241-210, 2019).

Table 1. Assessment of the eco-efficient EcoFlow portable fluid management system (F2S machine)

Statements	Technicians	Auto-care service center owners	Customers	Total mean	Interpretation
Overall performance of the EcoFlow F2S Machine meets my expectations.	4.88	4.90	4.95	4.91	Very Highly Acceptable
The machine is easy to operate and understand.	4.96	4.98	5.00	4.98	Very Highly Acceptable
The machine is portable and convenient for field and workshop use.	4.95	5.00	4.98	4.98	Very Highly Acceptable
The size and weight are suitable for daily operation.	4.83	4.85	4.90	4.86	Very Highly Acceptable
The machine operates safely with minimal noise.	4.90	4.92	4.96	4.93	Very Highly Acceptable
The machine is easy to transport between work locations.	4.98	5.00	5.00	4.99	Very Highly Acceptable
The overall design and layout are user-friendly.	4.91	4.94	4.97	4.94	Very Highly Acceptable
Grand Mean	4.92	4.94	4.97	4.94	Very Highly Acceptable

Overall, the evaluation demonstrates that the EcoFlow F2S Machine successfully combines technical functionality with user-centered design. Beyond improving maintenance efficiency, the integration of multiple fluid management operations within a single portable platform supports cleaner production by reducing equipment redundancy, minimizing fluid handling, and promoting environmentally responsible automotive servicing. These characteristics are consistent with sustainable engineering approaches that encourage resource conservation and pollution prevention within industrial maintenance operations (UNIDO, 2022; UNEP, 2023).

Actual performance testing of the eco-efficient ecoflow portable fluid management system (F2S machine)

The operational performance of the EcoFlow F2S Machine was evaluated by determining the average time required to transfer one liter of automotive fluid under each operating mode. The objective of the performance test was to determine the efficiency and operational

consistency of the developed prototype when handling automotive fluids with different viscosity characteristics.

As shown in Table 2, the Filling 1 (F1) function recorded the shortest average transfer time of 31.84 seconds per liter, whereas Filling 2 (F2) required an average of 33.18 seconds per liter. The difference between the two filling operations was only 1.34 seconds, indicating that the pumping mechanism maintained stable performance despite variations in fluid viscosity. This relatively small difference suggests that the selected pumping system is capable of providing reliable fluid transfer across a range of commonly used automotive lubricants.

Table 2. Actual performance testing of the EcoFlow F2S machine (Average transfer time per liter)

Operation	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean
Filling 1 (Medium Viscosity)	30.9 sec	31.5 sec	32.0 sec	32.7 sec	32.1 sec	31.84 sec
Filling 2 (High Viscosity)	32.6 sec	33.1 sec	33.5 sec	33.8 sec	32.9 sec	33.18 sec
Suction (Low Viscosity)	50.8 sec	51.9 sec	52.6 sec	53.1 sec	53.6 sec	52.40 sec

The slightly longer transfer time observed for the higher-viscosity fluid is consistent with the fundamental principles of fluid mechanics, whereby increasing viscosity produces greater resistance to flow and consequently requires additional pumping effort to maintain fluid movement. Therefore, the observed variation represents an expected physical characteristic of fluid transport rather than a limitation of the developed system. The stable performance recorded during repeated trials further demonstrates the reliability of the pumping mechanism and the suitability of the selected components for portable automotive fluid management applications.

The Suction (S) function recorded an average extraction time of 52.40 seconds per liter, representing the longest operating time among the three operating modes. This finding is expected because suction-based extraction depends on the generation of continuous negative pressure to remove fluids, whereas filling operations utilize positive pumping pressure for fluid delivery. Despite the longer operating time, the suction mechanism maintained consistent performance across all five trials, indicating stable vacuum generation and reliable extraction capability during routine maintenance operations.

From an engineering perspective, the performance results demonstrate that the EcoFlow F2S Machine provides dependable operation across its three integrated functions while maintaining consistent transfer efficiency under different operating conditions. The ability to perform filling and extraction using a single portable, battery-powered device represents a significant operational advantage over conventional maintenance practices that require multiple independent machines. This integration reduces equipment handling, shortens maintenance preparation time, and improves service flexibility, particularly during mobile servicing and roadside vehicle maintenance.

Beyond operational efficiency, the developed system contributes to environmentally responsible automotive servicing. Controlled filling and fluid extraction minimize accidental spills and improve the collection and recovery of used automotive fluids, thereby reducing the risk of soil and water contamination associated with improper fluid handling. Cleaner and more controlled maintenance practices are consistent with the objectives of sustainable engineering and cleaner production, which emphasize pollution prevention, efficient resource utilization, and waste minimization (Anastas and Zimmerman, 2018; UNEP, 2023). Furthermore, integrating multiple maintenance functions into a single portable device reduces equipment redundancy and material consumption, supporting eco-efficient engineering practices that contribute to more sustainable industrial operations (Ashby, 2022; UNIDO, 2022).

Overall, the combined findings from user evaluation and technical performance testing demonstrate that

the EcoFlow F2S Machine successfully achieved the objectives of the study. The prototype exhibited high operational acceptability, reliable fluid transfer performance, excellent portability, and strong user satisfaction while simultaneously promoting environmentally responsible automotive maintenance. These findings indicate that the developed system has considerable potential for application in automotive repair shops, mobile service operations, technical training institutions, and roadside maintenance services. Moreover, by improving fluid handling efficiency while reducing the likelihood of hazardous fluid loss and unnecessary equipment use, the EcoFlow F2S Machine supports broader sustainability initiatives aligned with the principles of green engineering and the United Nations Sustainable Development Goals, particularly SDG 9 (Industry, Innovation and Infrastructure) and SDG 12 (Responsible Consumption and Production) (United Nations, 2015).

CONCLUSION

This study successfully developed and evaluated the Eco-Efficient EcoFlow Portable Fluid Management System (EcoFlow-PFMS), a portable and rechargeable device that integrates fluid filling and suction functions into a single compact unit for automotive maintenance. The prototype achieved a Very Highly Acceptable overall rating (grand mean = 4.94), indicating high user satisfaction with its functionality, portability, ease of use, safety, and overall design.

Performance testing demonstrated consistent and reliable operation across all three functions, confirming the system's capability to efficiently handle automotive fluids with different viscosity levels. The integration of multiple fluid management operations into one portable device improves maintenance efficiency while reducing dependence on multiple pieces of equipment.

Furthermore, the EcoFlow-PFMS supports environmentally responsible automotive servicing by minimizing fluid spillage, improving fluid recovery, and promoting cleaner and more resource-efficient maintenance practices. Overall, the developed system represents a practical, reliable, and sustainable engineering innovation with strong potential for application in automotive workshops, mobile servicing, and roadside maintenance.

IMPLICATIONS

Biosciences and environmental science

The findings of this study demonstrate that the Eco-Efficient EcoFlow Portable Fluid Management System (EcoFlow-PFMS) has practical implications for both biosciences and environmental science by promoting cleaner and more sustainable automotive maintenance practices. The system enables controlled filling, transfer, and recovery of automotive fluids, thereby reducing fluid spillage and minimizing the potential release of hazardous contaminants into soil and water. Improved fluid management contributes to pollution prevention and supports the protection of ecosystems that may be adversely affected by improper disposal of waste oils and other automotive fluids.

From an environmental engineering perspective, the integration of multiple fluid management functions into a single portable device promotes resource efficiency by reducing equipment redundancy and encouraging responsible handling of hazardous materials. The portability and operational efficiency of the EcoFlow-PFMS also make it suitable for use in workshops, mobile servicing, and remote maintenance operations where environmentally sound fluid management is often challenging.

The study further contributes to sustainable engineering by demonstrating how practical technological innovation can improve maintenance efficiency while supporting cleaner production and responsible resource use. Consequently, the EcoFlow-PFMS has the potential to support the implementation of environmentally responsible automotive servicing and contribute to the achievement of the United Nations Sustainable Development Goals, particularly SDG 6 (Clean Water and Sanitation), SDG 9 (Industry, Innovation and Infrastructure), and SDG 12 (Responsible Consumption and Production).

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

1. Optimize the prototype design by reducing its overall weight and dimensions through the use of lightweight, durable materials while maintaining structural strength and operational reliability.
2. Enhance system functionality by incorporating features such as digital flow measurement, battery status monitoring, pressure sensors, and automatic shutoff mechanisms to improve operational accuracy, efficiency, and user safety.
3. Improve the suction mechanism by optimizing pump capacity and fluid flow performance to increase extraction efficiency, particularly for higher-viscosity automotive fluids.
4. Conduct long-term field evaluations under actual workshop and mobile servicing conditions to assess the durability, energy consumption, maintenance requirements, and reliability of the EcoFlow-PFMS during extended use.
5. Perform comparative performance and economic analyses against commercially available fluid management systems to determine the technical competitiveness, cost-effectiveness, and commercialization potential of the developed technology.
6. Investigate the environmental benefits of the EcoFlow-PFMS by quantifying its effectiveness in reducing fluid spillage, hazardous waste generation, and environmental contamination, thereby providing stronger evidence of its contribution to sustainable automotive maintenance.

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