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Performance Improvement of Hydraulic Excavator Efficiency: A Literature Review

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ABSTRACT

Excavators dominate heavy-duty jobs worldwide. As a major construction machine, their enhanced productivity in work has led to a strong demand for them. Concerns for the environment, increased efficiency, and energy conservation all reflect this goal. Several studies on these matters Automation in construction equipment, particularly hydraulic excavators, has gained popularity among producers and academics. This article examines articles about environmental concerns, efficiency enhancements, and energy (storage and evolving) issues in hydraulic excavators from a number of databases. This article reviews the technology of hydraulic excavators, covering their performance, related components, energy use, efficiency, and future opportunities. Research questions addressed include: How do hydraulic excavators work, what are the components, what is the role of maintenance in maintaining the performance of hydraulic excavator systems, what are the latest innovations in development for hydraulic excavator systems that can improve efficiency and reliability, and how can new technologies help reduce the impact on the environment. The method used to answer the research questions is SLR. The results of this article illustrate that excavator efficiency and performance depend on the architecture of the component layout, technology, systems and operational machinery used. The energy regeneration system serves to capture and store the potential energy generated during excavator operation. This stored energy can be reused to help power the hydraulic system, reducing the need for additional energy input.

1. Introduction

There are millions of excavators worldwide that dominate projects such as construction, mining, and other heavy-duty jobs that operate using hydraulic systems. Hydraulic excavators are operated at various sites due to their versatility, operating properties, and ease of maintenance, making them very popular among users especially in several types of heavy work such as excavation and material lifting. Earthmoving work often done in development projects accounts for a large percentage rate in the use of hydraulic excavators [1]. As a major construction machine, their enhanced productivity in excavation and building work has led to a strong demand for them. This desire is represented in energy savings, improved efficiency, and environmental concerns [2,3].

Several studies on the subject have been ongoing for many years now [1, 3-7]. The application of automation in construction machinery, especially hydraulic excavators, is a hot topic for manufacturers and researchers. In this automation requires techniques such as setting and operating levers simultaneously to perform various tasks, as well as operator skills and proficiency in automating several tasks to increase the efficiency and performance of hydraulic excavators [8-10]. Hydraulic excavator performance is influenced by several factors, such as work cycle time, excavator type and volume, soil depth, rotation angle, system and transmission, and work cycle time greatly affect excavator performance. Of these factors, the working cycle time of excavator operations consists of the time required to pick up, swing the load, dump, and swing empty. While the excavator cycle time is highly influenced and highly dependent on operating conditions and parameters such as excavator size, bucket capacity, digging depth, swing angle, dumping conditions, relative height, site conditions, material type, excavator operator skills, and weather conditions [2,11].

There are several key methods of optimization on hydraulic excavators including the installation of supporting attributes [7,10,12,13,14], advanced hydraulic technology [4,6,11,14-22], and so on. While every method is unique, they all follow the same core premise. The majority of them utilize several valves [3]. a diesel engine that typically acts as the power source and a set of four-side spool valves that regulate the actuator's movement in a variable displacement pump. In order to match the engine output power to the load power, several valves are also utilized to move the pump through the pilot system pressure. The four actuators will get oil from one or more pumps, and the oil distribution process involves throttling, which uses a lot of energy [4,9]. Only 23% of the engine power is used when operating an excavator due to the low energy efficiency of the pump, the 30% low energy efficiency of the hydraulic control system, and the 90% low energy efficiency of the mechanical system. The machine's average efficiency is only about 35%. The machine's overall energy efficiency is extremely low and inversely relates to the emissions it produces [9]. This is because the multivalve uses throttling to control the flow rate as well as the assist energy that is wasted in the form of heat during the excavator's duty cycle.

There have been many articles that discuss excavator optimization, such as discussing hybrid excavators in energy saving, system structure, and energy saving strategies [12]. However, there are no articles that discuss energy saving strategies, systems affected by liquid oil hydraulic and selection on excavators.

Based on this background, the author wants to write a review paper on the issue of the environment, improving efficiency and energy (storage and growing) on hydraulic excavators. In this article, we review Hydraulic Excavator technology, including the performance, related components, energy, efficiency, and future opportunities of hydraulic excavators. Specific research questions are discussed based on Research Question (RQs):

- How do hydraulic excavators work?
- What are the hydraulic excavator components?
- What is the role of maintenance in maintaining the performance of excavator hydraulic?
- Are there any recent innovations in the development of hydraulic systems for excavators that can improve efficiency and reliability?
- How can new technologies help reduce the environment impacts?

To answer these RQs, we conducted a Systematic Literature Review (SLR) with 20 related articles examined in the last five years from 2019 to 2023. Then, the selected studies were further analyzed to determine the type of information that is relevant to the development and trend of automation and the influence and optimization of energy through efficiency and performance of a hydraulic excavator. The result of this review is expected to provide an overview to researchers related to the development of existing research related to hydraulic excavators that focus on automation to improve efficiency and energy but also environmentally friendly to be able to find originality and novelty of their next research.

2. Methods

This article is an in-depth literature review with the methods described in detail as follows:

2.1. Article Selection

In preparing the data, it is necessary to search data using the screening and paper selection method, with detailed criteria are shown in **Table 1**. So that the data obtained is appropriate and relevant to related research. The search was conducted on September 5th, 2023 with details as in **Figure 1**.

Table 1 Method Use For Screening Paper

Database	**ScienceDirect, Semantic Scholar, Google Scholar**
Article type	Scientific articles published in peer-reviewed journals
Search query ("TITLE")	("Excavator") AND ("Hydraulic") AND ("Efficiency")
Time frame	From 1st January – 1st September 2023
Screening & paper selection procedure	Full paper available; article in English; article in the engineering or manufacturing domain; article related to energy saving; article related to efficiency
Removal criteria	Review articles (and generic articles) are removed

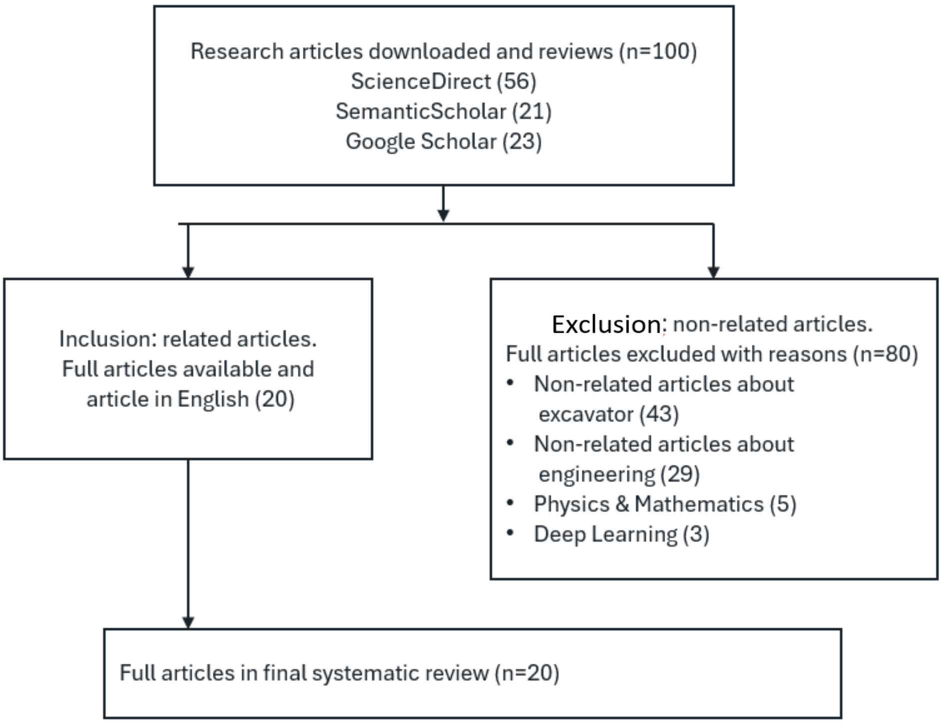

Figure 1 Paper selection.

Based on **Figure 1**, searching for articles based on keywords found 100 related articles from the 3 databases we used. After we did the screening criteria and paper selection, we only used 20 articles (20% of the total 100 articles).

2.2. Article Review Process

After the article selection process is complete, the author then downloads 20 articles and reviews the articles by answering 5 predetermined RQs, conducting discussions, and providing conclusions.

3. Results and Discussion

3.1. Keyword Analysis

The keywords provided by the authors of the selected papers have been analyzed. **Figure 2** shows the distribution of article fields in the journal database. The search involved many disciplines, such as automation, engineering, math and science, and others. A statistical analysis of publication sources from the last 5 years (2019-2023) was conducted to determine the preferences of manuscript selectors. Most of the Hydraulic Excavator related papers reviewed out of a total of 100 published articles are in Engineering (57), followed by Energy (19), Environmental Science (8), Earth and Planetary (5), Sciences (5), Computer Science (3), and Chemical Engineering (3). In answering the RQs, the authors reviewed the most articles in Engineering (15), followed by Energy (2), Environmental Science (2), and Earth & Planetary (1) with a total of 20 articles reviewed.

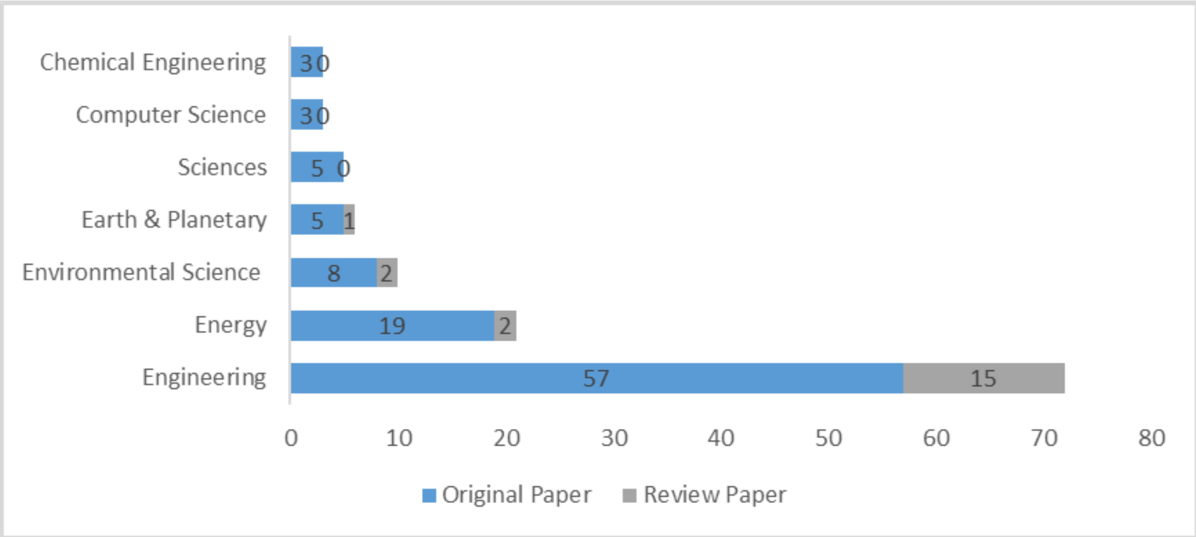

Figure 2 Distribution of the paper in the database.

3.2. Article Review Summary

Furthermore, the summary results of the article reviews that have been carried out are as in **Table 2**.

Table 2 Article Review Summary

References	RQ1	RQ2	RQ3	RQ4	RQ5
Influence of the excavator hydraulic system efficiency on the productivity [2]	The excavator's hydraulic circuits receive pressurized hydraulic oil from the engine, which enables the machine to execute fundamental functions like extending and retracting the inner arm, raising and lowering the boom, rotating the tool with the swivel head, opening and closing the tool, and swinging.	The unit is made up of a pump, manifold, bucket, arm, linear and rotary motors (which are synonymous with appiliance). The linear motor, which includes the inner arm, boom stroke, and tool motors. the rotary motor, like the motor that turns the swing body or the head.	The hydraulic oil will affect the measurement, such as pressure, flow rate, and the temperature of the hydraulic oil.	The swing hydraulic circuit is identified as a suitable circuit for innovation based on its significant percentage in the average tested cycle time and high-2 power loss, after evaluating the power losses and efficiencies of the hydraulic circuits.	Excavation operations can be completed more quickly and effectively with a more efficient hydraulic system, which can minimize power losses and increase productivity through improved hydraulic circuit design and performance. This can lessen the time and materials needed for building projects, thereby lessening their environmental impact as a whole.
Energy saving of hybrid hydraulic excavator with innovative powertrain [12]	It focusing on the boom system. Under actual working conditions, the boom constantly rises and falls.	Hydraulic cylinders operate the boom, arm, and bucket, which are the main parts. The remaining parts also include generators, converters, super-capacitors, electric motors, and valves.	-	The engine's speed and torque are managed by the Electric Hydraulic Continually Variable Powertrain (EHCVP) system.	Adopting the EHCVP can lower the engine's energy consumption, and the engine's operating points are situated in the high efficiency range. The electric motor and hydraulic pump displacement are controlled in order to optimize the engine working points.
Energy Management Strategies for Hybrid	The way hybrid construction machinery	In order for HCM, including excavators, to	-	HCM energy management techniques emphasizing	The goal of real-time (RBS) energy management

Construction Machinery: Evolution, Classification, Comparison and Future Trends [7]	(HCM) operates involves combining our understanding of chemistry, electricity, heat, liquids, and machinery. It generates, transmits, and transforms complex energy, power, and information flows in order to function.	function and manage energy, its constituent parts hydraulic systems, hydraulic pump-motors, hydraulic accumulators, and energy storage devices are essential.		energy reuse and recovery. These tactics fall into two categories: optimization-based tactics (OBS) and rule-based tactics (RBS). Hydraulic systems, hydraulic pump motors, hydraulic accumulators, and energy storage devices are examples of HCM components.	strategies is to maximize the internal combustion engine's (ICE) operating point. RBSs can contribute to environmental sustainability by preserving energy and lowering emissions by guaranteeing the ICE runs more efficiently. Optimize the HCM systems' control strategy for OBSs, another kind of energy management strategy.
Power Matching and Energy Efficiency Improvement of Hydraulic Excavator Driven with Speed and Displacement Variable Power Source [9]	The hydraulic fluid's flow and pressure can be adjusted to convert it into linear motion, which allows the excavator's arms, booms, and buckets to move. With an excavator, the operator can dig, lift, and move materials, among other things.	A hydraulic excavator is comprised of multiple parts, such as an actuator, control valves, hydraulic cylinders, hydraulic pump, and power source. An electric motor or a diesel engine usually serves as the power source.	-	Utilizing intelligent control strategies and speed-variable power sources, such as frequency-conversion electric motors, entails designing a power source/valve combined control strategy for system flow matching as well as using hydraulic accumulators to balance the power source's load during motor starting.	In order to reduce electric power consumption and emissions during idle and partial load conditions, energy efficiency can be increased through the use of speed variable power sources and intelligent control strategies. Innovative designs for construction equipment, like electric excavators powered by frequency conversion electric motors, can address noise levels, process dynamics, and energy efficiency to lessen their negative effects on the environment.

Design and Research on Electro-Hydraulic Drive and Energy Recovery System of the Electric Excavator Boom [10]	The excavator boom's electro-hydraulic drive and energy recovery system enables the recovery of the boom's gravitational potential energy using the electric excavator's original battery.	The system consists of the following parts: pressure cylinder, hydraulic cylinder, hydraulic valves (HV), variable hydraulic pump/motor (VPM), high-pressure accumulator (HPA), low-pressure accumulator (LPA), battery, motor, and other parts.	-	With four operating modes Electrodynamic drive, hydraulic drive, hydraulic regeneration, and electric regeneration a new electro-hydraulic drive and energy recovery system is designed for the electric excavator boom.	An important factor in the economic improvement of electric hydraulic excavators is the energy recovery system and electro-hydraulic drive for excavator booms. It seeks to enhance the energy regeneration and utilization of hydraulic excavators by concentrating on the reciprocal conversion of mechanical, electric, and hydraulic energy.
Study on energy efficiency characteristics of the heavy-duty manipulator driven by electro-hydraulic hybrid active-passive system [13]	-	Hydraulic cylinders, hydraulic accumulators, hoses and seals, valves, fluid reservoir, control system	-	An electrically active driving system and a hydraulically passive driving system make up the electro-hydraulic hybrid driving (EHHD) system. Utilizing hydraulic accumulators to recover and recycle lost gravitational potential energy is another innovation.	restoring and repurposing lost gravitational potential energy as well as increasing the driving system's efficiency. In order to solve these problems and boost energy efficiency, additional solutions include hydraulic accumulators, pump-control systems, and electric-mechanical actuators (EMA).
Potential Energy Recovery and Direct Reuse System of Hydraulic Hybrid Excavators Based on the Digital Pump [14]	With the combination of hydraulic power, mechanical parts, and operator control, hydraulic excavators can efficiently and effectively carry out a variety of	-	-	Three modes of operation pumping, energy recovery, and direct reuse are made possible by the application of digital hydraulic technology, more specifically digital displacement pumps (DDP), which improves overall	By enabling direct reuse of the recovered energy, the system lowers the input requirement and eliminates the need for additional energy conversion procedures. The AMESim simulation model's integration of mechanics,

	construction and excavation tasks.			efficiency and lowers energy consumption.	hydraulics, and electrics makes it possible to analyze the dynamic properties and assess the energy recovery system's performance.
Energy recovery for hybrid hydraulic excavators: flywheel-based solutions [16]	-	parts found in excavators, such as the hydraulic system, flywheel-based energy recovery systems, boom, stick, and bucket.	-	The application of energy recovery systems (ERSs) based on flywheels in hydraulic excavators appears promising.	Energy recovery systems (ERSs) based on flywheels have the potential to lower emissions and fuel consumption. It lowers the amount of fuel used and the emissions of harmful pollutants.
Experimental investigation of the influence of fluid viscosity on the efficiency of a crawler excavator [17]	The excavator's hydraulic system is made up of a number of actuators that are used for digging, blade elevation and lowering, and travel width adjustment. The primary pump powers hydraulic actuators, and its displacement volume is changed in response to the system's detected load pressure.	The hydraulic system of the excavator is made up of an electro-hydraulic pilot valve system, a main pump that powers hydraulic actuators, and a hydraulic-mechanical one-circuit load-sensing system. Additionally, there is a 15-liter hydraulic tank and a 21-liter hydraulic system on the excavator.	Certain characteristics, like temperature stability and viscosity index, are required of the hydraulic fluid. By taking these things into account, producers can create systems that minimize oil aging, lessen the need for frequent oil changes, and increase the excavator's overall longevity and efficiency.	The impact of fluid viscosity on a crawler excavator's efficiency, as hydraulic oil viscosity plays a major role in system performance. Inlet and outlet control edges are realized by intelligent control via independent metering.	Examining the impact of hydraulic oil viscosity can help minimize fuel use and CO2 emissions, which will lessen the negative effects on the environment. Throttling points and pertinent heat emissions can be found in the hydraulic system by measuring the pressure and temperature distribution within the system.
Simulated research on large-excavator boom based on hydraulic energy recovery [18]	The excavator uses arm and bucket cylinders to help with excavation and handle heavy loads during the process. The	The boom, stick, bucket, cab, upper section, and walking part are the principal parts. The main valve, hydraulic cylinder,	-	used LMS Imagine to design a new hydraulic type with an accumulator acting as a reversible energy storage component and a variable pump/motor acting as an	Energy recovery technology is essential for increasing the energy efficiency of hydraulic excavators and reducing energy consumption because it recovers and repurposes the

	material is lifted and turned by the boom cylinder and the rotary motor to the necessary unloading position once the excavation action is finished.	variable pump/motor, and accumulator are additional parts.		energy conversion element in order to save energy.AMESim software in lab.	potential energy released during the lowering of the boom. Thermal energy dissipation can be minimized with the aid of energy recovery technologies.
Comparative Study of the Influence of the System Architecture on the Accuracy of Hydraulic Cylinder Working Movements [19]	-	-	Viscosity of the liquid and other liquid parameters have an impact on the movement of hydraulic cylinders.	created a hydrostatic power system, which offers higher system efficiencies and is used in machines to reduce power consumption.	-
Ageing Process of Hydraulic Oil in Single-Bucket Excavators in Rock Mining [20]	-		While the ageing process in hydraulic systems cannot be entirely stopped, it can be considerably slowed down by using high-quality oils.	The OPCom Portable Oil Lab, a portable oil diagnostic system, was used to study the ageing process of hydraulic oil in single-bucket excavators used in rock mining.	-
The effects of control methods on energy efficiency and position tracking of an electro-hydraulic excavator equipped with zonal hydraulics [23]	The excavator's hydraulic system gives it the strength and adaptability it needs to carry out a variety of routine tasks, like leveling and digging with varying payloads.	Two lithium-ion batteries and electro-mechanical linear actuators have replaced the hydraulic system. It was made up of a displacement variable pump with independent metering-in and metering-out that was powered by	By proactively addressing maintenance needs, operators can minimize the risk of unexpected breakdowns, improve safety, and optimize the overall performance of the	Benefits of zonal hydraulics include reduced power consumption, easier automation, and reduced pressure losses when using Direct Driven Hydraulics (DDH). Due to direct control by an electric servo drive, it was demonstrated that the	Excavators can use less energy and operate more efficiently thanks to zonal hydraulics' decreased power and pressure loss rates. Higher system energy efficiency and improved position tracking performance can be attained simultaneously by

		an electric motor with variable speed.	excavator hydraulic system.	controller design had an impact on the performance and efficiency of the excavator under study.	implementing sophisticated control techniques, such as the flow-rate-matching feedforward plus PID controller.
A Power-Split Hybrid Transmission to Drive Conventional Hydraulic Valve Controlled Architectures in Off-road Vehicles: The Case of a Mini-Excavator [24]	-	-	-	modern hydraulic actuation in conjunction with a power-split hybrid transmission between the prime mover and the supply pump. It permits independent engine and pump speed control.	In order to reduce fuel consumption while maintaining the hydraulic system architecture's market acceptability, the authors suggest utilizing a power-split hybrid transmission between the prime mover and supply pump in conjunction with cutting-edge hydraulic actuation to enhance efficiency. Efficiency is increased because the suggested solution enables independent control of the pump's and engine's speeds.
A Boom Energy Regeneration System of Hybrid Hydraulic Excavator Using Energy Conversion Components [22]	-	The system consisted of electrical motor/generator and hydraulic pump/motor components that transformed hydraulic energy into electrical energy and stored it in a battery for use in later cycles.	-	The creation and application of a hybrid hydraulic excavator's energy regeneration system. It is essential to recover energy and minimize energy consumption in excavators, particularly in boom systems.	With the suggested control method, the boom cylinder performed well in terms of position and velocity. During operation, the energy management strategy based on discrete time-optimal control guaranteed component safety and position tracking performance.

Research on a new energy-recovery system for hybrid hydraulic excavators [21]	Boom descent, mining, boom promotion and slewing, unloading, and slew reset make up an excavator's duty cycle. When the boom is lowered, a controller that operates hydraulic excavators switches the machine to operate in energy recovery mode automatically.	An excavator's hydraulic system is made up of parts like the accumulator, side cylinders, middle cylinder, main pump, and main control valve.	-	Energy recovery systems (ERSs) come in three primary varieties: mechanical, hydraulic, and electric. The system for recovering and utilizing energy is built around multiple cylinders.	The system lowers greenhouse gas emissions and fuel consumption by recovering and regenerating the wasted energy during the boom's lifting and lowering operation. When compared to conventional energy recovery systems, the system is more efficient and environmentally friendly because it does away with the need for complicated operations, an extra oil charge, and additional booster devices. the decrease in greenhouse gas emissions and fuel consumption.
Optimization of energy regeneration of hybrid hydraulic excavator boom system [6]	During energy regeneration, a hydraulic motor is used to regulate the cylinder velocity. The hydraulic motor's rotational speed is also controlled to control the cylinder velocity.	The energy regeneration boom system's use of a variable displacement hydraulic motor and flow control valve to adjust the generator's torque, speed, and flow. The battery and generator are also mentioned as parts of the mechanism that transforms mechanical energy into electric energy for storage.	-	The energy regeneration boom system outperforms traditional systems in terms of energy regeneration efficiency. To control torque, speed, and flow, it makes use of a flow control valve and a variable hydraulic motor. Additionally, the system has a control strategy to lower the generator's setup power and guarantee system safety in high-velocity and large-load modes.	An energy regeneration efficiency that was higher than that of conventional boom systems was attained by the hybrid excavator thanks to an improved energy regeneration boom system. Energy conversion and regeneration are significantly impacted by the hydraulic motor's hydro-mechanical and volumetric efficiency.
Development of a Comprehensive	Hydraulic cylinders are used in the operation of	It is made up of a bucket, arm, and boom.	-	A comprehensive driving cycle classification	establishes load demand power and boom recoverable

Driving Cycle for Construction Machinery Used for Energy Recovery System Evaluation: A Case Study of Medium Hydraulic Excavators [25]	excavators to regulate the movement of the arm, bucket, and boom. An excavator's arm, bucket, and boom all work together to accomplish various tasks. Using pedals and joysticks, the operator manipulates these movements.			construction method and an energy-saving efficiency evaluation method for medium hydraulic excavators based on real operating data	power models based on machine sensing data after analyzing general driving cycle variables for excavators with various energy-saving schemes. The suggested methodology for constructing comprehensive driving cycles using the sample space is deemed dependable and exhibits potential in assessing the energy-saving effectiveness of novel energy-saving concept systems.
Efficiency of electro-hydraulic servo steering for heavy construction vehicles [26]	-	-	-	The electro-hydraulic servo steering system (EHSSS) efficiency model takes into account the nonlinearities in the hydraulic and mechanical aspects of the steering system. Steering angle and equivalent load are two factors that affect the EHSSS's efficiency.	By identifying areas for improvement, EHSSS can result in operations that are more energy-efficient and have a smaller environmental impact. Reducing energy waste and enhancing overall system performance can be achieved by optimizing the EHSSS according to load conditions and steering angles. This will have a positive impact on the environment.
Energy recovery and utilization system of excavator boom	When performing tasks like digging, loading, and unloading, a traditional	This traditional excavator (TE) operates with a boom, arm, bucket, and	-	An energy recovery and utilization system (ERUS) based on flow regeneration	The ERUS identifies the ideal parameters for increased performance by analyzing the

based on flow regeneration and balance theory [27]	excavator releases a large amount of potential energy as heat.	cylinders as its main components.		and balance theory for the boom of a conventional excavator (TE).	effects of key parameters on the energy-saving efficiency of the ERUS. Utilizing hydraulic accumulators (HAs) and hydraulic-hydraulic circuits, it recovers and makes use of the excavator boom's potential energy. It increases energy consumption and decreases flow loss by rerouting oil flow and storing energy in the balancing cylinder.

3.3. Answering RQs

Improving efficiency and reliability in hydraulic excavators is influenced by several factors including unit type, systems and machinery, technology, as well as the operator's ability to operate the unit. A brief explanation of these factors is:

- Unit Type: Variations or models of excavators that are distinguished by size, capacity, specifications, and other special features. Choosing the right type of unit will affect performance and efficiency in a particular job [24,25].
- Systems and engines: the choice of transmission, engine (conventional, hybrid or electric), hydraulic system and other specialized systems can affect the performance of the excavator in performing various tasks [22].
- Technology: The use of additional equipment either conventional or automatic and technological trends can support the performance of an excavator. This additional equipment is widely applied to engine and system parts such as valves, motors, capacitors, pumps, and others [9,12,14,19].
- Operator skills: The skills and proficiency of the operator can affect the performance of the excavator as the operator can manipulate the work in performing the task, minimize the risk of unexpected damage, and improve safety [9,13,15,25].

Based on the results of the article review, RQ1 of "What is the working principle of hydraulic excavators?" has been answered. All these excavator work functions are performed by combining hydraulic power, mechanical components and operator controls to perform various tasks. The use of hydraulic and fuel systems (conventional or electric) in excavators is useful for transferring power and providing ample power to perform strenuous tasks such as construction, excavation, lifting and more.

In conjunction with the RQ2, an excavator generally consists of the Chassis (frame), engine, hydraulic system, Boom (arm), Bucket (digging tool or bucket), lubrication and cooling system and other attachments controlled by hydraulic cylinders. In addition, other components that can be found in both hybrid and electric excavators are electric engines and motors, generators, converters, supercapacitors, valves, and valves. Additional equipment is determined by the type of unit and its requirements.

In conjunction with RQ3, the drive of the excavator is hydraulic, therefore the selection and good maintenance of hydraulic oil is very important. Hydraulic oil as a large power provider must have a good index. Hydraulic oil must be at a temperature within a safe range, have anti-corrosion and anti-wear properties and be a lubricant for components in the hydraulic system. Furthermore, good hydraulic oil is environmentally friendly hydraulic oil, which has the ability to biodegrade.

In relation to RQ4, the efficiency and performance of an excavator depends on the architecture of the component layout, technology, systems and operational machinery used. For example, using a variable displacement pump, the hydraulic system can adjust the flow rate and pressure according to the load requirements. In addition, the load sensing system monitor the pressure and flow requirements of the hydraulic system and adjusts the pump output accordingly. This ensures that the pump only delivers the required amount of hydraulic fluid. The use of an electronic control system enables precise control of the hydraulic system. The system can adjust parameters such as flow rate, pressure, and speed, based on real-time feedback from sensors. There is also an energy regeneration system that captures and stores potential energy generated during excavator operations, such as when the boom is lowered or the bucket is dumped. This stored energy can be reused to help power the hydraulic system, reducing the need for additional energy input. Performing regular maintenance and proper lubrication of the hydraulic system is essential for optimal performance and efficiency. This includes routine inspections such as checking for leaks, maintaining proper fluid levels, and using high-quality hydraulic fluid.

In conjunction with RQ5, additional devices to support the technology developed can make a big impact, especially in terms of energy and efficiency in excavators. This is supported by the use of the right systems and machines so as to obtain reduced energy used so as to reduce carbon emissions and other environmental impacts. Many of the systems on excavators implement energy regeneration along with hybrid engines to achieve targets in efficiency and energy. Excavators that have good operational systems and reliability will reduce environmental impacts such as wasted gas emissions, power loss, and more.

4. Conclusion

This article discusses the improvement of efficiency and energy, as well as a review of environmental issues in hydraulic excavators. Using the literature review method, the data taken comes from several articles from ScienceDirect, SemanticScholar, and Google Scholar. The search keywords used were based on ("Excavator" AND "Hydraulic" AND "Efficiency"). The search was conducted on September 5, 2023 and 20 articles were obtained. The topic of improving efficiency and energy and reviewing environmental issues in hydraulic excavators has not been discussed. After the review process, it can be concluded that the efficiency and performance of an excavator depends on its component layout architecture, technology, systems and operational machinery used. The hydraulic system, with the variable displacement pump, load sensing system, electronic control system and energy regeneration system, can adjust the flow rate, pressure and speed based on load requirements. Moreover, the selection of the right hydraulic fluid can optimize the performance of the hydraulic system which can improve efficiency and extend service life. Also to perform regular Maintenance and proper lubrication, including leak checks to optimize the performance of the hydraulic system that can improve efficiency and extend service life.

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