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Technical Note

Efficiency and Comfortability of a Newly Developed Pedal-Operated Reciprocating Pump Device

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Insufficient water supply in rural areas has prompted many communities to opt for manually operated water pumps. However, these water pumps can be demanding to operate and may pose physical difficulties for users. This study addresses this issue by developing a pedal-operated water pump with a modified reciprocating piston pump and a seating system that users can comfortably operate for a prolonged period of time. The study tested thirty respondents categorized into three groups based on demographic parameters such as age, weight, and height. Results demonstrated that the newly developed pedal-operated water pump achieved its highest mechanical efficiency of 62.73% and discharge efficiency of 99.50%. Furthermore, the study found that age, weight, and height have a very low correlation with cycling speed, with correlation levels of 3.93%, 1.83%, and 1.83%, respectively. The cycling speed also exhibited a low correlation level of 2.17% with the calories burned by the user. Thus, the developed water pump only required minimal physical effort from users of various age groups to produce adequate water outputs of up to 40.46 liters per minute. This study highlights the efficiency and user convenience of the newly developed pedal-operated water pump, which can be useful in communities for domestic and agricultural water supply.

Keywords: comfortability; discharge efficiency; mechanical efficiency; pedal-operated reciprocating pump; water pump.

1. Introduction

Water scarcity is a significant challenge that hinders the socio-economic development of any nation. Despite being abundant in water reserves, the Philippines is still vulnerable to water shortages due to multifaceted factors that threaten its people, environment, and sustainable development. In 2020, approximately 7460 water facilities were constructed across the country. However, nearly half of these constructed structures had limited capacities to transport water to far-flung provinces, especially in isolated and geographically challenged areas [1]. The region of Mindanao Island, home to two of the four major groundwater reserves in the Philippines, namely the Agusan Ground Water Reservoir and the Pulangi Ground Water Reservoir [2], still faces unsophisticated and unequal water distribution systems across many regions. This issue leaves many marginalized and impoverished communities living in rural areas vulnerable to water scarcity [3]. As a consequence, the affected communities have to rely on local communal water stations since it is assumed to be the only way to have water in their homes [4]. These community water stations often have manually operated pumps, which play a crucial role in harnessing ground and surface water. However, due to their labor-intensive mechanism and the amount of physical effort needed to power such pumps [5], these pumps can be challenging to utilize and operate, particularly for vulnerable groups such as children and the elderly. As a result, many Filipino families are forced to walk several kilometers to fetch water from distant water sources [6].

The manually operated pumps come in many different designs (i.e., hand pumps, pedal- operated pumps, and foot pumps) that are best suited to the needs of the family or community. Given their simple working mechanism, these pumps have been widely used globally for irrigation and domestic purposes [7]. For instance, this was exemplified by McKay [8] in his work on the Water Buffalo design in Africa. He aimed to develop a child-friendly, low-cost, and mass-producible bicycle-powered pump for African families. Using a recycled bicycle frame that houses a plastic gearbox for the impeller, following the principle of a centrifugal pump, he conducted his experiment 5 m away from a creek with fourteen African respondents. Additionally, Water Buffalo pump's friction calculation losses revealed that fast flow rates of 1 L/s with a 1-inch diameter had significant friction losses attributable to suction side air leaks. His parameters for measuring the water flow of the pump at various input power levels and vertical heads resulted in a 55% pumping efficiency.

Subsequently, this pump was further developed by Abhijith *et al.* [9] through an experimental study on pedal-powered water pumping and purification system. Their study focused on designing a working model that integrates an upright bicycle, a centrifugal pump, and a purification system [8]. Moreover, the bicycle pump design mechanism and experiment parameters of McKay [8] and Abhijith *et al.* [9] were further supported by the study of Dixit *et al.* [10], which also integrated a centrifugal pump into a bicycle [8]. They investigated the relationship between elevation and discharge flow rates and confirmed that the higher the elevation, the lower the discharge flow rates. Also, their study suggested that the performance of their prototype was heavily dependent on the effort exerted by the cyclist. Thus, the study concluded that pumping head and flow discharge rates were directly related to the input power generated by the cyclist.

Furthermore, Radha and Dorathi [11], who utilized an upright bicycle and a centrifugal pump as the core water pumping system, elaborated on this analysis and suggested in their study that the fabrication of a bicycle-driven water pumping and power generation system directly correlates with the relationship between weight and output discharge. Another significant insight into the input power generated by the cyclist was provided by Amda [12] in his work on the development and analysis of the pedal-powered water pumping system. However, his prototype did not utilize the frame of a bicycle. Instead, it followed an unconventional approach by utilizing a chair to address issues related to comfort during prolonged cycling time, thereby suggesting such an approach increases water flow rate. The performance of his pedal-powered water pumping system was able to garner a flow rate of 0.15 L/s at its maximum elevation of 5 m.

Contrary to the above-mentioned pedal-operated water pumps, the pedal-operated water pump prototype created by Islam *et al.* [13] differed from the centrifugal pumping mechanism employed by McKay [8], Abhijith *et al.* [9], Dixit *et al.* [10], and Radha and Dorathi [11]. In their study, the pedal-operated water pump prototype adopted an approach still utilizing an upright bicycle but used a reciprocating pump as its core water pumping system. During the trial experiments, Islam *et al.* matched different combinations of piston valves and check valves to determine the best combination for achieving high pumping efficiency without compromising user convenience. Their comprehensive review suggested that the combination of a piston valve that had a rubber flap-mounted perforated cast-iron disc with dimensions of 11 mm and four slot openings per square cm, along with a check valve that also contained a rubber flap-mounted perforated cast-iron disc sized at 7 mm and ten slot openings per 6.45 square cm, constituted the best assemblage for a high pumping efficiency along with a pedal operation that was both comfortable and not tedious in comparison to the conventional hand water pump.

Numerous studies in the literature have established various design approaches for developing effective manually operated bicycle water pumps. In reference to the study of Ejiko *et al.* [14], they clearly mentioned the critical factors needed in designing a manually operated bicycle pump. Their study emphasized the importance of considering design parameters such as the type of pump, discharge flow rates, the design of the bicycle or pedal frame, and user convenience. Moreover, it was also discussed that determining the discharge flow rate was a critical parameter to meet the intended water supply. Conversely, pumping efficiency and user convenience were identified as crucial parameters for minimizing physical effort while maximizing water output.

The established studies [8–11, 13, 14] were mostly restricted to the utilization of an upright bicycle and investigation of the relationship between elevation and discharge flow rates. However, they failed to emphasize the significance of user comfortability and how it directly affects the input power generated by the users, consequently affecting the water flow rate. In addition, these studies did not address varying seat designs that could enhance convenience while operating for users, including vulnerable populations (i.e., children and the elderly). Furthermore, the abovementioned studies overemphasized the use of centrifugal pumps in their pedal-operated pump prototypes and predominantly focused on efficiencies and water output obtained from using centrifugal pumps [8]. Among these studies, only Islam *et al.* [13] were able to fabricate a pedal-operated pump that uses a reciprocating piston water pump as its core water pumping system. However, they still failed to consider comfortability as one of its parameters. With this, there is a gap in the existing literature regarding the relationship between a reciprocating piston water pump as part of a pedal-operated water pumping system and user convenience. Thus, it is also vital to develop a pedal-operated reciprocating piston water pump that could minimize the power input and the physical effort required by the user while simultaneously maximizing water flow output.

This current study aims to develop a hydraulic pedal-operated water pump device that incorporates design parameters and recommendations from Dixit *et al.* [10], Amda [12], and Islam *et al.* [13]. Consequently, this study develops a newly designed pedal-operated reciprocating pump to minimize the physical effort without compromising water outflow. The study has five specific objectives. First, it creates a pedal-operated pump design through SOLIDWORKS® 2021. Second, it simulates the pressure of water inside the pump using the SOLIDWORKS® 2021 Flow Simulation. Third, it constructs an actual prototype from the solid model design and simulation results, testing it with selected independent variables (e.g., age, height, weight, rotational speed) from users. Fourth, it verifies data obtained from field experiments and calculates head losses necessary for computing the mechanical efficiency and discharge efficiency of the newly developed pedal-operated reciprocating pump. Lastly, it establishes relationships between gathered data and calories burned as measured variables for comfortability through correlation and regression analysis using IBM SPSS Statistics software.

2. Materials and methods

2.1. Design framework and simulation of the newly developed pedal-operated reciprocating pump

2.1.1. Design framework. The newly developed pedal-operated reciprocating pump in this study was designed with various alterations and enhancements that were necessary for refining the water pumping system. The modified improvements were incorporated to increase pumping efficiency and overall user convenience. A careful selection of the principal components (i.e., water pumping mechanism and seating arrangement) was conducted. Figure 1 shows the design framework of the newly developed pedal-operated reciprocating pump used in the water pumping system.

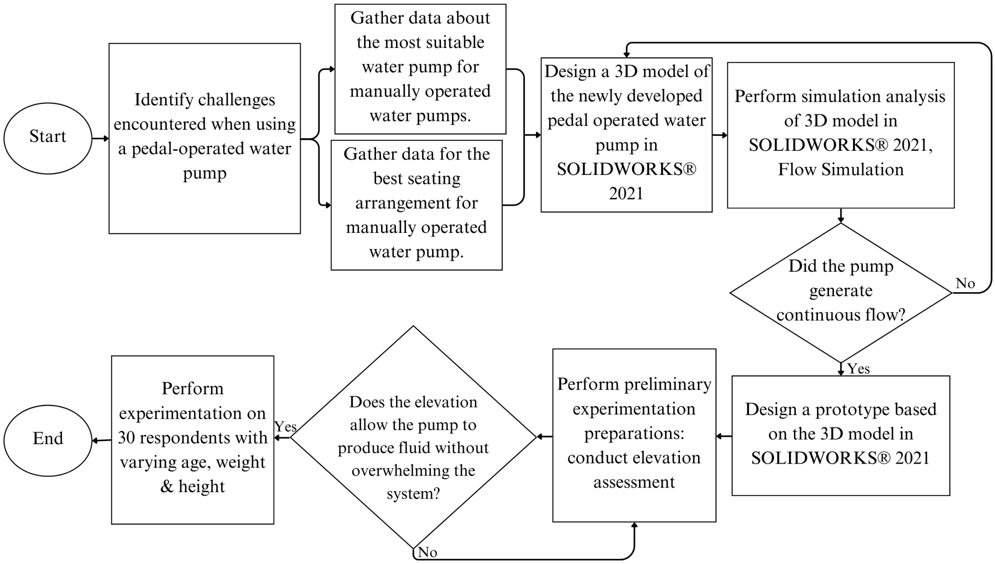

Fig. 1. Design framework for the water pumping system.

Concerning the water pumping mechanism in the design framework, Chandramouli *et al.* [15] published a study comparing two widely used water pumps: (1) a reciprocating piston pump, and (2) a centrifugal pump. They mentioned that the main distinction between these pumps is that centrifugal pumps are considered low in efficiency; however, they could run at higher speeds. On the other hand, reciprocating water pumps are highly efficient yet run at lower speeds. In this design framework, the reciprocating water pump was considered for its significance in terms of comfortability without compromising water output. It was also necessary to understand that a user could not maintain higher speeds for prolonged periods. Working within this framework, it was evident that there was no need to provide a high-speed pump. Additionally, CHANDRAMOULI *et al.* [15] also emphasized that reciprocating water pumps were more likely to produce the same output flow even with fluctuating power inputs due to the varied degrees of human exertion.

Regarding the seating system, in contrast to the studies presented by McKAY [8], DIXIT *et al.* [10], and RADHA and DORATHI [11], which utilized an upright bicycle frame, this study followed the recommendations of AMDA [12] and ELLER [16]. which suggested using a chair to improve and prolong cycling time, translating into increased discharge output. The design also modified the chair setup to be easily configured and adjusted to suit the users' preferences and comfort during operation. Likewise, the modified seating arrangement highlighted various features, such as side handles for stability and an improved chair for ease of mounting and dismounting, for a more comfortable and user-friendly experience for the respondent.

2.1.2. Model development. The newly developed pedal-operated reciprocating water pump was designed using SOLIDWORKS® 2021 [17] software. Figure 2 shows the isometric three-dimensional (3D) model of the pedal-operated water pump, which represents a collection of various design approaches and modifications from the design framework (Fig. 1) relevant to the enhancement of the system's overall functionality, efficiency, and convenience.

FIG. 2. Design of the newly developed pedal-operated reciprocating water pump.

The 3D model is composed of three main components, as shown in Fig. 3: (a) water pumping mechanism, (b) pedal system, and (c) seating system. This study referred to the design approach of ISLAM *et al.* [13] for the water pumping system, McKAY [8], DIXIT *et al.* [10], and RADHA and DORATHI [11] for the pedal cycling system, and the seating arrangement referred to the recommendations of AMDA [12] and ELLER [16].

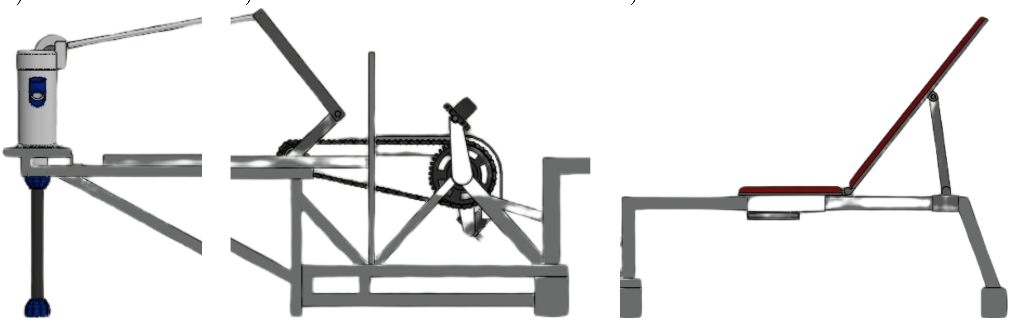

Fig. 3. Pedal-operated reciprocating pump:
a) water pumping mechanism, b) pedal system, c) seating system.

2.1.3. Simulation and performance analysis. After the 3D model was designed, the water pumping mechanism (Fig. 3a) underwent a mesh independence test with respect to the maximum von Mises stress of the design model to determine the increased degrees of freedom due to the increase in mesh density. Once convergence was achieved, a mesh quality check was performed. In order to achieve accuracy in the mesh independence test, a uniform-perfect tetrahedral element was preferred. Then, the simulation was immediately followed.

The simulation of the water pumping system was executed using SOLIDWORKS® 2021 Flow Simulation Premium [18]. The purpose of this simulation was to investigate the behavior of water pressure inside the water pumping mechanism (Fig. 3a) of the newly developed hydraulic pedal-operated reciprocating water pump (Fig. 2) under ideal conditions. The Philippine Agricultural Engineering Standard [19] defines ideal conditions as ambient conditions with optimal temperature and pressure, perfect calibration and equipment alignment, and no external factors or disturbances. Considering this context, the ideal design was checked for its mechanism during simulation analysis before construction.

2.2. Prototype development of the newly developed pedal-operated reciprocating pump

2.2.1. Actual prototype. Following the comprehensive modeling procedures and simulation process, the newly developed prototype of the pedal-operated reciprocating water pump was constructed, as shown in Fig. 4.

In the mentioned figure, the brown leather seat (1), a 50 mm × 10 mm square bar (2), and a 10 mm × 30 mm angle bar (3) are the parts of the seating system. The pedal system comprises a chain drive (4) and a driven sprocket (5). The 10 mm marine plywood (6) is utilized to protect the respondent's legs from striking the drive sprocket (7). Moreover, the 1-inch pillow block (8) is used to posi-

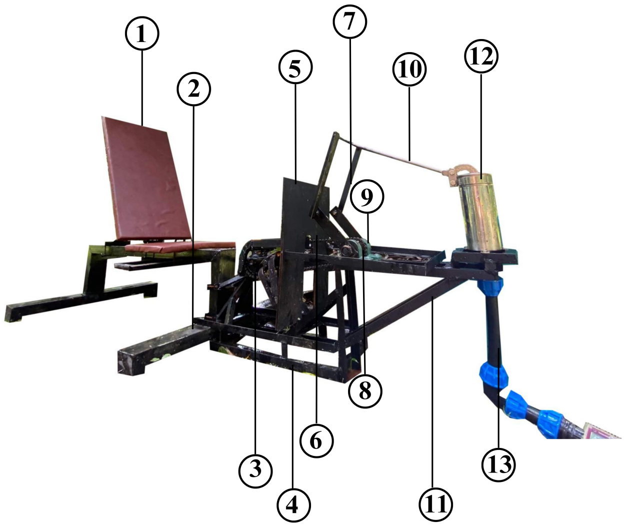

FIG. 4. Members and parts of the newly developed pedal-operated reciprocating pump.

tion the 10 mm × 20 mm angle bar (9) in place. Attached to the 10 mm × 20 mm angle bar is the force lever (10) that powers the reciprocating pump (13). Additionally, a 15 mm × 30 mm angle bar (11) is added between the pedal system and the water pumping system to maintain the stability of the newly developed hydraulic pedal-operated reciprocating pump. Lastly, the stainless-steel reciprocating pump (12) is the core pumping mechanism. These materials were bought from a local hardware store in Davao City, Philippines.

Moreover, these materials were selected based on the published studies of EJIKO *et al.* [14] and DIXIT *et al.* [10]. They stated that the essential factors in developing and constructing a pedal-operated pump are: (1) pump type, and (2) accessibility or affordability for low-income groups. The first factor indicated by EJIKO *et al.* [14] indicates that the pump type should be feasible for the intended use and readily available. According to RAO and NAIDU [20], there were essential considerations in pump type selection: (1) pump capacity, (2) initial maintenance costs, and (3) speed of rotation and power required. With all these factors considered, this study utilized a stainless-steel reciprocating piston pump with a 1-inch diameter inlet pipe and a pumping capacity of 20 L/min. The second factor considered was material selection. In choosing the materials, it was necessary that the materials were durable enough to be suited for the intended working environment. MOHAMMED [21], SHIRBHATE *et al.* [22], and MOGAJI [23] used metals as the body frame of their pumping system.

In this study, the prototype used galvanized iron (GI) rectangular tubes for its seating section, angle bars for the cycling and pumping sections, and crank gears obtained from scrap metal. Furthermore, the actual prototype had a dimension of 2.5 m in length, 1.5 m in height, and 0.7 m in width. The seating system spanned 1.3 m to accommodate comfortable seating configuration and adjustments. Moreover, the pedal system measured 0.7 m in length. The links connecting the pedals to the reciprocating pump consisted of a steel rod measuring 0.3 m in length, allowing enough space for users to efficiently translate pedal motion into vertical oscillations. The reciprocating pump, encased within a cylindrical structure, had an outer diameter of 32 mm and a height of 25.5 mm.

2.2.2. Operational water pumping system. The schematic diagram of the operational water pumping system of the newly developed pedal-operated reciprocating pump is presented in Fig. 5. The principal components of the overall system are: (1) the seating system, (2) the pedal system, and (3) the reciprocating water pump. With this, the main goal of the iterative process was to draw water from point 1 and transport it to point 2 with an elevation of z_2 (m) as a reference for its hydraulic performance.

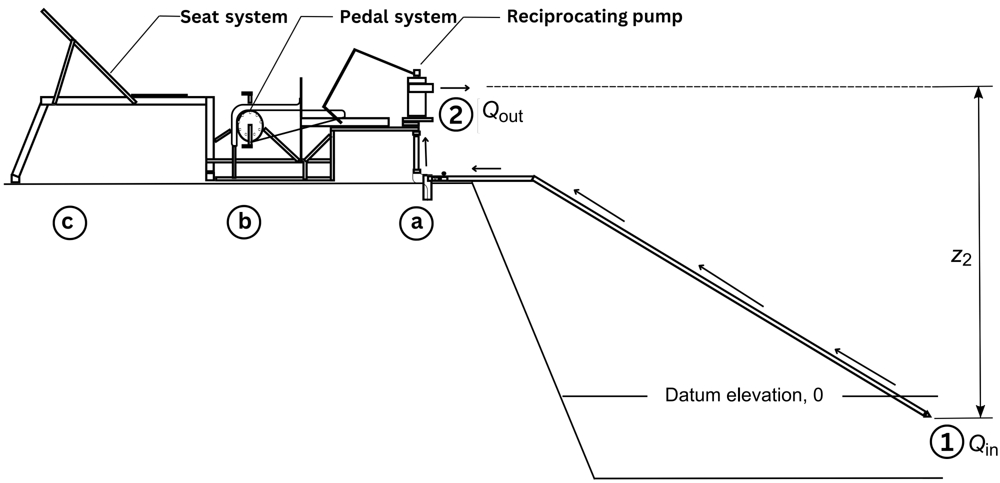

FIG. 5. Schematic diagram of the water pumping system.

Furthermore, the process of translating human-powered mechanical energy into water output flow begins when a user configures the seating system. Consequently, as the user exerts a certain amount of physical effort on the pedal system, rotational movement is translated to vertical oscillations (up-and-down movements) via the chain and linkage system. The vertical motions generated by the linkage system are then transferred to the reciprocating water pump, powering the water pump via vertical forces. Through this translation of energy, the piston rod located within the water chamber of the reciprocating water pump functions under pressure differences created within the piston chamber, thus forcing water to flow [15]. The upward stroke of the piston rod was considered to be the suction stroke, whereas the downward stroke was the compression stroke. Moreover, the upward stroke of the piston rod created a vacuum and opened the inlet valve while simultaneously closing the outlet valve and drawing water into the piston chamber. Followed by a downward stroke, the inlet valve was closed due to pressure while the outlet valve was opened, forcing the water contained within the piston chamber to be discharged [24]. Additionally, the discharge input and output are denoted as Q_{in} and Q_{out}, respectively (m^3/s).

2.3. *Preliminary preparations prior to experimentation*

2.3.1. Site area, elevation assessment, and demographic variables. During the selection of an appropriate site location for examining the actual performance of the newly developed pedal-operated reciprocating pump, this study identified an area within the vicinity of a 22-hectare farm in Barangay Talandang, Calinan District, Davao City, Davao del Sur, Philippines. Presented in Fig. 6 is the topographic view of the chosen location. The selection of the area was based on several factors, namely, community demographics, geographical landscape, community issues and challenges towards water scarcity, and accessibility.

FIG. 6. Topographic view of the site area (Google, 2023 [25]).

First, the chosen location is inhabited by farmers and fruit harvesters who have various demographic characteristics, including age, weight, and height. The diversity in demographic selection was a critical parameter in determining the efficiency and comfortability aspects of the newly developed pedal-operated reciprocating pump. Secondly, the topography of the chosen location showed that the farm is surrounded by fruit-bearing trees that require water allocation all year around. A small creek that runs across the farm is also found in the site location. However, with recurring power outages in the area, the on-site diesel-operated water pumps utilized by the farmers were inadequately reliable. Furthermore, the accessibility of the site was also a crucial consideration. The chosen location is well connected by roads, making it convenient for the respondents. Hence, the farmland became a viable site location to test the performance of the newly developed pedal-operated reciprocating pump. The field experimentation was conducted from the 19th to the 26th of August in 2023. The testing operations were carried out from 10:00 am to 2:00 pm.

Moreover, based on the simulation analysis performed using SOLIDWORKS® 2021 Flow Simulation, the elevation and location of the actual prototype suggested that the reciprocating water pump would be at its optimal performance under ideal conditions. A factor that mirrored ideal conditions in actuality was the topographic location and elevation of the water pumping system. Within the site area, the identified elevation was 3.6 m and was the ideal location for the prototype, providing an optimal point for experimentation. The actual elevation of the water source is shown in Fig. 7.

Fig. 7. Actual elevation for the water pumping system.

Generally, it was deemed necessary to identify the precise elevation that would allow the water pump to function efficiently without imposing excessive strain on the users during the pedal operation. The site location was carefully observed to place the actual prototype, as shown in Fig. 8. Hence, it focused on finding the balance between two critical aspects of the water pumping system. First, the generated flow rate of the water pump had to be sufficient without overwhelming the system. Second, the user's performance and the ease of operation had to be considered to ensure that the pumping technology could be comfortably managed without exerting excessive physical effort.

Fig. 8. Actual prototype of the newly developed pedal-operated reciprocating water pump.

Another critical emphasis on the preparation prior to experimentation was the experimental setup structured around diverse demographics located within the farm vicinity. The experimental setup was designed to assess its comfortability and usability across diverse demographics. These experimental groups were carefully divided into categories based on age, weight, and height, since they possessed different physical capabilities as requirements needed to operate the pedal-operated reciprocating pump. Different factors, such as cycle operation, height adjustments, and force exertion, could significantly influence the user's convenience and overall comfortability. This approach ensured that the newly developed pedal-operated reciprocating pump could accommodate a broader spectrum of users with varying demographic profiles.

Moreover, measuring instruments such as a flow meter and pressure meter were configured beforehand to produce accurate results during the actual experimentation. This study prepared two working spaces to tally the users demographic data (e.g., name, age, weight, and height) before cycling. Thereafter, gathering data on each respondent's demography was conducted, and each respondent was given five minutes to utilize the water pumping device. Within the allotted time, the respondents were given personal discretion and autonomy to stop whenever they felt fatigued. Subsequently, a pulse oximeter was attached to the respondent's finger. Once the respondent's given period ended, data were gathered on the flow meter (L/min), the pressure meter (kPa), the revolutions per minute (rpm), and the pulse beat per minute (beats/min) in preparation for the calculations on the comfortability and efficiency outputs.

2.3.2. Specifications of measuring tools and devices. In this experiment, a precise measuring tool was used to quantify the collected data. The different tools and devices used in the field experiment, along with their measured parameters, are presented in Table 1. The experiment began after the adjustments and calibrations were made.

Table 1. Details of measuring tools and devices used in the experimentation*.

Device/tool	Measured parameter	Measuring range	Measuring accuracy
Pressure gauge	Input pipe pressure	0–60 psi	±0.25%
Flow meter	Input pipe flow	0–5 bar	±1.00%
Tape measure	Elevation between the prototype and the reservoir	0–100 ft	±0.001%
Tally counter	Number of cyclic rotations	0–9999 counts	–
Stopwatch	Period of the cycling activity	–	0.01 s
Pulse oximeter	Beats per minute by the user between pre-cycling and post-cycling	–	±2.00%
Weighing scale	Respondent's weight	0–150 kg	±0.1 kg
Plastic bucket pail	Output volume	65 L	–

* Two initial trials were conducted for data measurements to ensure calibration before proceeding to actual experimentation.

Before the operation period, the parameter started to record the respondents' weight (kg) and height (m), which were quantified via a weighing scale and a measuring tape. Thereafter, the respondent's pulse beats per minute (beats/min) were gathered using a pulse oximeter in pre-cycling and post-cycling periods. Furthermore, the pressure gauge, which was attached to a tee pipe, recorded corresponding values to the maximum point scale (kPa). The output water flow was collected using a container, and its internal dimensions were measured using a steel measuring tape. The volume of water output was quantified twice: first by calculating the water level of the container as its height (m), which was measured using the steel tape, and second by the readings of the flow meter (L/min). The cycling rotations of the respondents were recorded using a 4-digit tally counter.

2.4. Performance assessment of the respondents

The respondent parameters were essentially considered to obtain comprehensive data for the water pump's performance analysis. Listed in Table 2 are the number of observations with varying demographic characteristics (e.g., age, weight, and height). Thirty respondents for experimentation were gathered via the snowball sampling method [26].

Table 2. Respondent data based on the demographic profile.

Observation	Gender	Age [year]	Weight [kg]	Height [m]
1	Male	13	40.40	1.372
2	Female	13	37.80	1.463
3	Male	13	39.70	1.615
4	Male	13	36.20	1.585
5	Male	14	36.70	1.524
6	Male	14	38.30	1.494
7	Female	15	43.00	1.615
8	Male	16	60.20	1.706
9	Male	16	44.00	1.737
10	Female	16	40.60	1.524
11	Male	17	49.00	1.767
12	Female	19	45.00	1.584
13	Male	21	69.70	1.707
14	Female	23	82.50	1.585
15	Female	23	45.00	1.585
16	Male	26	69.00	1.737
17	Male	28	65.00	1.646
18	Male	30	53.60	1.646
19	Male	33	62.60	1.737
20	Male	33	48.40	1.524
21	Male	33	67.00	1.706
22	Female	34	62.00	1.615
23	Female	39	67.20	1.554
24	Female	40	63.00	1.645
25	Male	44	58.20	1.584
26	Male	45	66.70	1.676
27	Female	47	54.00	1.615
28	Male	48	55.70	1.615
29	Male	58	64.00	1.615
30	Male	60	60.40	1.768

This study referred to the study of DIXIT *et al.* [10], where they had gathered a small sample of three subjects and recorded their respective parameters: (1) age, (2) weight, and (3) height. They found that the respondents required a 5-minute rest after a continuous duration of 15 minutes. Thus, the performance assessment methodology of their study was adopted in this present study, wherein the respondents were classified according to their demographic information and were allotted five minutes of cycling time with the autonomy to stop whenever they felt tired or fatigued.

2.4.1. Age parameter. According to the published paper by TOLENTINO and SIGUA [27], children are capable of developing adequate motor skills by the age of ten. MERCE *et al.* [28] indicated that the amount of physical activity of children has a direct proportional relationship with the learning age of cycling. They also found that physical activities promoted positive physical fitness, such as balance, and motor coordination. Conversely, older age groups from fifty to eighty-three encountered positive feedback in their cognitive and physical aspects. In this study, the respondents' ages were recorded and categorized into three groups. The first group was in the age group of thirteen to nineteen and consisted of twelve participants, with the youngest and oldest ages being thirteen and nineteen, respectively. The second group was in the age range of twenty to thirty-nine and consisted of eleven participants, with the eldest being thirty-nine years old and the youngest being twenty-one years old. Lastly, the third group consisted of seven respondents aged forty and above, with the eldest being sixty years old.

2.4.2. Weight parameter. As stated by USMAN *et al.* [29], adult-bodied individuals with a weight of 50 kg and above could operate the pump freely. Their respondents had weights ranging from 59 kg to 92 kg, with an average weight of 75.4 kg. However, the said study only garnered five respondents, who were then subjected to the pump at different elevations. They concluded that the weight of the individual was directly proportional to the discharge of the pump. RADHA and DORATHI'S [11] also studied the respondents' weights and pump output as well as cycling speed. The respondents weighed 52 kg, 60 kg, and 68 kg, respectively. Their study showed that the weight of the cyclist was directly proportional to the pump's and dynamo's outputs. In the context of this study, the recorded weights were categorized into three age groups, and the respondents were asked to step on the weighing scale for data recording. The collected data was also used for calculating the calories expended by the respondents.

2.4.3. Height parameter. In the analysis of the published study by PHILLIPS and HOPKINS [30], at an elite level, the morphology of a cyclist (i.e., height and stature) affected their performance in various fields of specialization. However, according to Choudhary [31], there was no significant relationship between height and cycling. It was also emphasized that height was significantly influenced by both genetics and a healthy lifestyle. In terms of cycling performance, the height of a person was inversely proportional to their performance because aerodynamic performance was dependent on various other factors. After the interview was conducted in this study, the age and the respondent's height were measured using a tape measure. The recorded measurements were used for calculating the calories used by the respondents.

2.5. Relationship between respondent's calories and comfortability

A manually pedal-operated water pump that demanded a high level of physical exertion resulted in more calories burned. By contrast, a low level of physical exertion also required a fewer calories to be burned. The significance of calories burned during pedal operation of the newly developed hydraulic pedal-operated reciprocating pump gave insight into assessing the amount of physical effort and exertion needed to operate the newly developed water pumping system. Hence, this study utilized recorded parameters of age, weight, height, and pulse readings to determine the calories exerted by each respondent. Equations 1 and 2 from the study of Reiaz *et al.* [32] were used to calculate the calories burned during operation according to the gender of the respondents.

$$\text{Calories}_{(\text{male})} = \frac{[(\text{Age} \times 0.2017) - (\text{Weight} \times 0.09036) + (\text{Heart rate} \times 0.6309) - 55.0969]}{4.184} \times \text{Time}, \tag{2.1}$$

$$\text{Calories}_{(\text{female})} = \frac{[(\text{Age} \times 0.074) - (\text{Weight} \times 0.05741) + (\text{Heart rate} \times 0.4472) - 20.4022]}{4.184} \times \text{Time}, \tag{2.2}$$

Furthermore, the unknown variables presented in the equations were based on the recorded parameters of the respondent's age (years), weight (kg), heart rate (beat/min), and the duration of time recorded (min). It was explained by Carson [33] that the presented caloric equations assigned per gender were due to greater calorie expenditure variations between men and women. Both equations were used to calculate the approximate calories burned considering the age, weight, and heart rate of each respondent during the operation.

Moreover, the relationship between the input power generated and the comfort level of the newly developed pedal-operated reciprocating pump was crucial in determining its overall pumping efficiency and user experience. Calories burned during the experimentation process were directly correlated to the physical effort required to power a water pumping system. The term "calories burned" could also be defined as the input power generated required to operate a water pump [10]. This was exemplified when a respondent exerted more physical effort; it was expected that the input power generated by the user was higher than that of one who exerted less physical effort. Also, an efficient pumping operation allowed respondents to maximize water extraction with reduced physical exertion, potentially minimizing the input power generated with the pedal action. Dixit *et al.* [10] also stated that, in order to maximize water output, it was essential to prolong pedal operation. This suggested that a comfortable design had to be achieved to minimize physical strain and discomfort during pumping operations.

2.6. Validation of findings and calculations of efficiencies

To fully assess the performance of the newly developed pedal-operated reciprocating water pump, the gathered data from the experimentation was subjected to analysis. In this study, Bernoulli's equation was used to analyze the parameters involved in the water pumping system, such as elevation, velocity, and pressure heads from both the input and output of water inside the system (Vakil and Green [34]; Karthick *et al.* [35]; Ejiko *et al.* [14]). Moreover, Halvadar *et al.* [36] described Bernoulli's equation as points 1 and 2 in the reference illustration presented in Fig. 5, where the first point is the submerged pipe from the water source, while the second point is the water outflow. This equation was also used in the study of Celerinos and Sanchez-Companion [37] to relate the velocity, pressure, and elevation heads of the pump to its efficiency outputs, where the equation also incorporated the pipe friction losses from the input pipe. The equation is expressed as:

$$\frac{v_1^2}{2g} + \frac{p_1}{\gamma} + z_1 - hf_{1-2} = \frac{v_2^2}{2g} + \frac{p_2}{\gamma} + z_2, \tag{2.3}$$

where v_1 is the input velocity of the input pipe (m/s); p_1 is water pressure from the pressure gauge (kPa); hf_{1-2} is the calculated pipe friction loss of the input pipe (m); z_1 is the established datum line of the system located in the submerged input pipe (m); v_2 is the velocity output of the output discharge (m/s); z_2 is the distance between the established datum line and the outlet (m); p_2 is the atmospheric pressure experienced by the output discharge (kPa); g is the constant gravitational acceleration (m/s^2); and γ is the specific weight of water (kN/m^3).

In this experiment, the pressure head between points 1 and 2 was equal because there were no changes in pipe diameter. In addition, the pumping outlet was subjected to atmospheric pressure. Celerinos and Sanchez-Companion [37] simplified the expression of Eq. (2.3) as:

$$\frac{p_1}{\gamma} - hf_{1-2} = z_2. \tag{2.4}$$

The friction factor in the input pipe (hf_{1-2}) was derived from the Darcy-Weisbach formula for circular pipes. Equation (2.4) describes that the input head was dependent on the pressure head at the outlet and the pipe loss due to friction in the input pipe. The head loss due to pipe friction is expressed as:

$$hf_{1-2} = \frac{0.0826 f\, L\, Q^2}{D^5}, \tag{2.5}$$

where f is the pipe friction factor; L is the length of the delivery pipe (m); Q is the discharge output (m^3/s); and D is the diameter of the delivery pipe (m).

Halvadar *et al.* [36] specified that the pipe friction factor (f) was based on the water flow. The water flow was classified into laminar and turbulent flows. The Reynolds number (Re) was calculated to quantitatively categorize the water flow in the experiment. Celerinos and Sanchez-Companion [37] explained that the water flow is laminar if Re is less than or equal to 2000. Likewise, it is turbulent if Re is greater than 3000. In addition, the water flow transition phase is between 2000 and 3000. Equation (2.6) shows the calculations for the Reynolds number, and Eqs. (2.7) and (2.8) showed the calculations for the pipe friction factor.

$$\mathrm{Re} = \frac{v\, D\, \rho}{\mu}, \tag{2.6}$$

$$f_{\mathrm{Laminar}} = \frac{64}{\mathrm{Re}}, \tag{2.7}$$

$$f_{\mathrm{Turbulent}} = \frac{0.316}{\mathrm{Re}^{0.25}}, \tag{2.8}$$

where v is the velocity of the water in the delivery pipe (m/s); ρ is the mass density of water (kg/m^3); and μ is the water dynamic viscosity ($\mathrm{Pa}\cdot\mathrm{s}$). Halvadar *et al.* [31] recommended using water dynamic viscosity for a 20°C temperature in this experiment for simplification of calculation.

Also, included in the head losses in the water pumping system were the losses due to pipe fittings. These losses were described as pipe friction loss due to different bends and materials in the system. Equation (2.9) presents the formula for the minor losses:

$$H_{\mathrm{fittings}} = \frac{\sum K\, v^2}{2g}, \tag{2.9}$$

where $\sum K$ is the summation of the coefficient of pipe friction losses due to fittings in the water pumping system, since materials and fittings used in the newly developed pedal-operated reciprocating pump have different manufacturers.

In addition to the calculations, the performance of the newly developed hydraulic pedal-operated reciprocating pump was also determined by its efficiency output. It was classified as mechanical output efficiency and discharge efficiency, respectively. The mechanical efficiency (η_m) is measured by the comparison between actual drive torque and theoretical torque requirements [38]. Hence, 100% mechanical efficiency implies that the pump does not require torque to operate at zero pressure. However, mechanical and water frictions prevent it from achieving ideal efficiency. The mechanical efficiency equation is expressed as:

$$\eta_m = \frac{p\,Q_T}{T_A N} \times 100\%, \tag{2.10}$$

where p is the pressure recorded (kPa), Q_T is the theoretical water flow (m^3/s), T_A is the actual torque measured (N $\cdot$ m), and N is the number of revolutions per minute recorded of the pedal-operated reciprocating pump.

Lastly, Eq. (2.11) presents the use of Bernoulli's equation to evaluate the discharge efficiency (η_d) [38]. The discharge efficiency assesses the input Q_{in} and output Q_{out} of the discharge water flow. This efficiency shows a direct proportional relationship between input and output discharge. If the calculated value is low, it implies that the pedal-operated reciprocating pump produced a smaller discharge output than the water input:

$$\eta_d = \frac{Q_{\text{out}}}{Q_{\text{in}}} \times 100\%. \tag{2.11}$$

2.7. Statistical analysis

The correlation and regression analysis were used in this study to establish relationships between the independent variables of age, weight, and height, and the dependent variable of cycling speed by the respondents. Also, the cycling speed was independent if it was compared to the variable of the burned calories of the respondents as the dependent variable. The degree of correlation between the considered variables was measured using the Pearson correlation coefficient r, and the selection of hypothesis was determined by the 95% confidence level ($\alpha = 0.05$). This study formulated four null hypotheses. The first null hypothesis stated that there is no relationship between the age of the respondents and the recorded cycling speed. The second null hypothesis stated that there is no relationship between the weight of the respondents and their recorded cycling speed. The third null hypothesis stated that there is no relationship between the height of the respondents and the recorded cycling speed. To determine the indicators for the comfortability parameters, the fourth null hypothesis stated that there is no relationship between the cycling speed of the respondents and their burned calories during operation. On the other hand, all the alternative hypotheses stated that there were relationships between the considered variables. The collected data were then analyzed and interpreted according to statistical conventions. The researchers used the IBM SPSS statistics software version 22.0 [39] at the University Information Technology Office of Ateneo de Davao University, Davao City, Philippines, for the data analyses.

3. Results and discussion

3.1. Simulation analysis on the newly developed hydraulic pedal-operated reciprocating pump

The simulations of pressure in the water pumping system in SOLIDWORKS® 2021 Flow Simulation Premium [18] under ideal conditions are presented in Fig. 9. The illustrated diagrams map the strong and weak pressure points of hydraulic flow created throughout the water streamline. As shown in the figure, the meshing analysis indicated that the behavior of the water was unstable and turbulent once the suction mechanism of the pump was used, reaching up to 111.394 kPa. This pressure is generally not considered dangerously high in many common applications. However, the potential danger associated with a particular pressure level will differ depending on the context and the specific

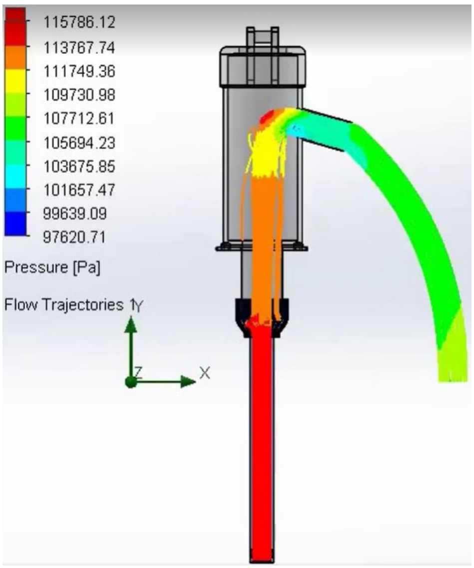

Fig. 9. Simulations of the water pumping system under ideal conditions.

system or equipment involved. In this case, 111.394 kPa was considered a normal operating pressure that was used for industrial and laboratory equipment. Moreover, the flow transitions to a laminar movement with a pressure of 90.379 kPa once the water flow enters the pump mouth was observed. Hence, this did not affect the performance of the pump because the simulation employs a constant pressure surge, and the component parts show no sign of wear and tear, and they remain stable.

Based on the colors presented, different hues signify varying water pressure levels. The color red represents the highest pressure point, while the color blue indicates the lowest pressure point. The visual representation of the simulated water pumping mechanism (Fig. 3a) shows that the optimal pressure points are located between the neck of the reciprocating pump and the middle of the water pumping chamber. This analysis also suggests that the chosen water pumping mechanism's performance simulated under ideal conditions is less likely to have water pressure fluctuations. It was expected that the efficiency of the newly developed hydraulic pedal-operated water pump would be sufficient to generate continuous water output discharge. Additionally, the simulation analysis finds that the reciprocating piston pump is an excellent design for the pedal-operated water pump and is used as a baseline for the actual setup of the water pumping system.

3.2. Performance analysis of the newly developed pedal-operated reciprocating pump

3.2.1. Respondents' calories, water pressure, and discharge output. The results of each respondent's burned calories, water pressure (gauge), and discharge output during the five-minute operation period are presented in Table 3. The calculated burned calories using Eqs. (2.1) and (2.2) showed a low result of 12.19 kcal and a high result of 62.64 kcal for group 1, a low result of 1.98 kcal and a high result of 47.88 kcal for group 2, and a low result of 5.43 kcal and a high result of 38.78 kcal for group 3, respectively.

These results were compared to the 36 kcal calories burned during normal cycling activity [40], which ranged from 20 km/hr to 22 km/hr with the same time duration period set in this study. From the comparison, nine out of twelve respondents in group 1 obtained values below 36 kcal, which suggested that the users were not exhausted during the entire operation. In group 2, eight out of eleven respondents obtained below 36 kcal, and six out of seven respondents for group 3 obtained below 36 kcal. The results confirmed that during the entire operation period, respondents were comfortably operating the newly developed pedal-operated reciprocating pump, which only required 47 rpm to 79 rpm of pedal operation for group 1 of ages 13 to 21 years old, 62 rpm to 92 rpm for

Table 3. Summary of gathered data during field experimentation and calculated head losses.

Observation	Cycling speed [rpm]	Calories [kcal]	Pressure [kpa]	Discharge [L/min]
1	47	20.39	19.480	20.04
2	65	52.88	25.685	29.39
3	67	20.46	20.169	35.78
4	73	28.38	21.548	40.46
5	79	18.01	18.790	10.17
6	56	22.36	18.790	29.33
7	47	25.80	16.722	24.80
8	68	12.19	18.790	13.07
9	48	30.89	18.790	25.04
10	57	40.35	22.238	28.23
11	64	62.64	20.859	15.39
12	76	26.40	18.790	9.29
13	89	28.95	17.580	21.20
14	87	47.88	25.685	13.65
15	83	44.21	18.790	9.29
16	60	11.38	20.859	20.0
17	93	7.02	25.685	19.75
18	68	18.53	27.754	35.4
19	70	44.67	24.475	11.91
20	74	26.60	18.790	22.65
21	62	1.98	20.859	11.33
22	68	30.80	24.306	34.3
23	63	34.72	26.375	34.6
24	51	38.78	20.859	28.23
25	59	22.17	25.685	34.0
26	56	16.21	19.480	29.4
27	73	29.60	27.064	38.6
28	35	15.11	13.964	15.4
29	75	8.33	15.343	13.94
30	44	5.43	16.722	24.69

group 2 of ages 23 to 39 years old, and 35 rpm to 75 rpm for group 3 of ages 40 to 60 years old. It was also observed during the operation period that the cycling techniques used by the respondents significantly impacted the obtained results. With varying cycling techniques, the findings suggested that the respondents had put considerable effort into powering the water pumping system.

Moreover, it was found in the study that the weight of respondents for groups 1, 2, and 3 varied from 38.3 kg to 82.5 kg. In the study conducted by Usman *et al.* [29], they suggested that the weight of the user allowed for an increased cycling force. However, in this study, these findings were not evident. The weight of the respondents had little to no influence on their cycling speed or performance. This was due to the seating arrangement that involved a chair instead of a saddle, wherein the weighted force of the respondent had no significance to the force required to power the pedal system. This study noted, following the suggestion of Amda [12], that saddle height was one of the factors that affected cycling performance, as it required the user to have a stable and comfortable seating position during the operation period. Hence, the newly developed pedal-operated reciprocating pump addressed the issue of comfortability, wherein the design provided an allowable adjustment and configuration of the seating system.

Furthermore, it was also found that the relationship between height and cycling speed had no effect on the obtained calories burned, as this was attributed to the cycling technique used by the respondents. This study observed that the users employed certain techniques to achieve an effective pedal operation period. Some of these techniques included: (1) pedal rhythm, (2) pace and momentum, and (3) body positioning. During the field experiment, the respondents exhibited various pedal rhythms, paces and momenta, and body positioning that reflected their own preferences during cycling. These observed techniques significantly influenced their cycling period and comfortability, thus increasing their discharge output. Respondents had various pedal rhythms, ranging from slow, slow-moderate, moderate, moderate-fast, and fast cycling. Most respondents tried different cycling rhythms that best suited their preferences during the first minute. Consequently, it was noticed that after the first minute, the respondents were able to find their pace and momentum. The interaction between pace and momentum reflected the respondent's endurance and strategy for a more consistent, efficient, and sustainable pace during cycling periods. Lastly, the study also revealed that respondents had different methods when it came to body positioning. Part of this body positioning focused on their balance and weight distribution. Although it was evident that body positioning was subjective for each respondent, they either leaned their backs on the back support or maintained a neutral sitting stance for their comfort.

Lastly, the water pressure recorded for operating the newly developed pedal-operated reciprocating pump ranged from 13.964 kPa (gauge) to 27.754 kPa (gauge), which was equivalent to the standard atmospheric pressure of 115.289 kPa (atm) to 129.079 kPa (atm). These results were very close to the simulated results of 111.394 kPa in standard atmospheric conditions under normal operating pressure in the SOLIDWORKS® 2021 Flow Simulation. From these obtained values, it was evident that the design was effective for both simulation and experimental results. Apart from water pressure, Table 3 also presents the results of discharge flow rate. The recorded discharge output ranged from 9.29 L/min to 40.46 L/min for group 1 (ages 13 to 21), 9.29 L/min to 34.6 L/min for group 2 (23 to 39), and 13.94 L/min to 38.6 L/min for group 3 (40 to 60). The recorded results were comparable to a typical water pump for residential usage, which can obtain 19 L/min [41]. Out of thirty respondents, twenty achieved a discharge rate beyond 19 L/min, which showed that the newly developed pedal-operated reciprocating pump was capable of providing a good quantity of water for any regular usage operation.

3.2.2. Head losses, calculated elevation, and difference in elevation head. The tabulated values of calculated pipe friction losses, total head losses, velocity, and the difference in elevation heads are presented in Table 4. The head loss results due to pipe fittings calculated using Eq. (2.9), ranged from 0.02 m to 0.034 m. On the other hand, the head loss results due to pipe friction calculated using the Darcy-Weisbach formula (Eq. (2.5)), ranged from 0.042 m to 0.504 m. These results were influenced by the transition of water flow and the relative pipe roughness in the water pumping system [42, 43]. These findings are supported by Guo *et al.* [44], who noted that in the transition of water flow, the friction factor experiences a monotonic change in pipes from smooth to fully rough. These also indicated that the surface roughness and the changes in sizes and dimensions of pipe fittings used in the water pumping system significantly affected the obtained total head losses [45].

On the other hand, the calculated elevation obtained during the experimentation affected the results of total head losses, ranging from 0.075 m to 0.5277 m, as shown in Table 4. Similarly, the calculated results for the velocity of water inside the water pumping system ranged from 0.3156 m/s to 1.178 m/s. It can be noticed that the velocity results were quite similar since the pumping system used a uniform pipe diameter. However, the varied results were evident due to the force exerted by each respondent during the cycling period. Hence, the velocity affected the discharge output as well as the attained elevation head because the water velocity was proportional to the hydraulic head gradient, indicating that water velocity changes could have impacted the gradient and subsequently affected hydraulic elevation. The effect of increased depth in high topography showed a lower water flow compared to the increase of hydraulic heads with elevation depth under lowlands [46].

Within this context, the study only set an elevation of 3.6 m based on the topographic location where the newly developed pedal-operated reciprocating pump was placed. The set elevation was then compared against the calculated elevation to verify the accuracy of the obtained elevation head using Bernoulli's

Table 4. Summary of results for the total head loss and results of the difference in elevation head.

Observation	Head loss due to pipe fitting [m]	Head loss due to pipe fiction [m]	Total head loss [m]	Velocity [m/s]	Set elev. [m]	Calculated elev. Z_2 [m]	Diff. in elev. head [m]
1	47	20.39	19.480	0.6810	3.6	3.59	(0.01)
2	65	52.88	25.685	0.9978	3.6	3.63	0.03
3	67	20.46	20.169	1.1562	3.6	2.69	(0.91)
4	73	28.38	21.548	1.1780	3.6	2.78	(0.82)
5	79	18.01	18.790	0.3451	3.6	3.91	0.31
6	56	22.36	18.790	0.9978	3.6	2.93	(0.67)
7	47	25.80	16.722	0.8394	3.6	3.04	(0.56)
8	68	12.19	18.790	0.4438	3.6	3.82	0.22
9	48	30.89	18.790	0.8394	3.6	3.25	(0.35)
10	57	40.35	22.238	0.8012	3.6	3.67	0.07
11	64	62.64	20.859	0.5227	3.6	3.94	0.34
12	76	26.40	18.790	0.3156	3.6	3.93	0.33
13	89	28.95	17.580	0.6319	3.6	3.46	(0.14)
14	87	47.88	25.685	0.4635	3.6	4.50	0.90
15	83	44.21	18.790	0.3156	3.6	3.93	0.33
16	60	11.38	20.859	0.6810	3.6	3.73	(0.13)
17	93	7.02	25.685	0.6046	3.6	4.33	0.73
18	68	18.53	27.754	0.8722	3.6	4.10	0.50
19	70	44.67	24.475	0.4043	3.6	4.44	0.84
20	74	26.60	18.790	0.6592	3.6	3.55	(0.05)
21	62	1.98	20.859	0.3846	3.6	4.09	0.49
22	68	30.80	24.306	1.1562	3.6	3.12	(0.48)
23	63	34.72	26.375	0.8066	3.6	4.08	0.48
24	51	38.78	20.859	0.9583	3.6	3.22	(0.38)
25	59	22.17	25.685	1.1562	3.6	3.26	(0.34)
26	56	16.21	19.480	0.9978	3.6	3.00	(0.60)
27	73	29.60	27.064	1.3145	3.6	2.97	(0.63)
28	35	15.11	13.964	0.6592	3.6	3.06	(0.54)
29	75	8.33	15.343	0.4733	3.6	3.44	(0.16)
30	44	5.43	16.722	0.8394	3.6	3.04	(0.56)

equation (Eq. (2.3)). Figure 10 showcases the difference between the calculated and set elevations. The highest calculated elevation was 4.50 m, while the lowest had a value of 2.97 m. The positive difference in results ranged from 0.03 m

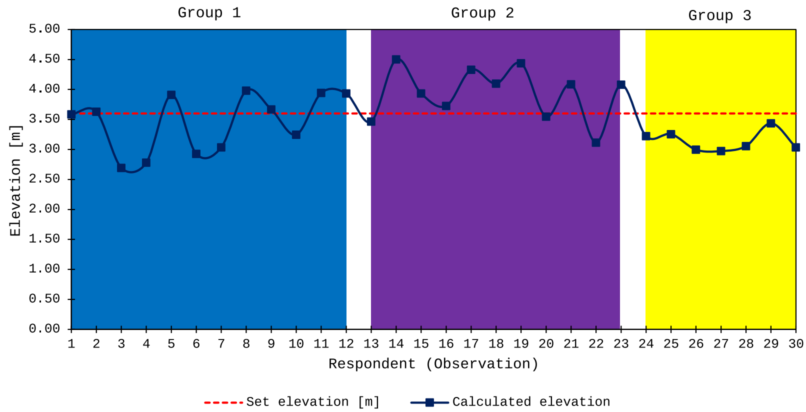

FIG. 10. The difference between calculated elevations and set elevations.

to 0.9 m, indicating that the results were above the 3.6 m set elevation. On the contrary, the negative difference in results ranged from 0.01 m to 0.91 m, indicating that the results were below the 3.6 m set elevation. This verification showed that the results were very close to the set elevation. The verification of Bernoulli's equation confirmed that the differences were influenced by the contribution of pipe friction, pipe fittings used, and the total losses.

Furthermore, some uncontrollable conditions were found during the experiment, such as the cycling position of the respondents, the wastage of water in the pump due to the pipe leakage, and the vibrations in the pedal operation, which also contributed to the difference in results. Hence, evident results indicated the elevation differences as depicted in the plotted figure.

3.2.3. Mechanical efficiency and discharge efficiency. The results for the mechanical efficiency and the discharge efficiency of the newly developed pedal-operated reciprocating water pump are shown in Table 5. These efficiencies were calculated using Eqs. (2.10) and (2.11), respectively. In the calculation, group 1 achieved the highest mechanical efficiency at 62.73%, while group 2 achieved the lowest mechanical efficiency at 17.08%. Similarly, group 1 achieved the highest discharge efficiency at 99.50%, while group 2 still achieved the lowest discharge efficiency at 4.17%. Generally, mechanical and discharge efficiencies were two critical parameters in assessing the overall performance of the water pumping system. In this study, the discharge efficiency represented the ratio of the actual discharge outflow rate divided by the actual inflow rate. Hence, the newly developed pedal-operated reciprocating water pump achieved a discharge efficiency of 99.50%, indicating minimal wastage of water.

Likewise, this study also employed mechanical efficiency to measure the input power generated by the water pumping system. The results showed the highest

Table 5. Results of mechanical efficiency and discharge efficiency.

Observation	Mechanical efficiency [%]	Discharge efficiency [%]
1	32.39	47.55
2	26.30	59.19
3	24.63	99.50
4	24.88	94.97
5	57.63	47.41
6	25.15	87.04
7	25.81	81.50
8	45.70	51.16
9	30.02	58.16
10	27.54	72.34
11	41.37	42.41
12	62.73	48.27
13	30.89	21.36
14	47.33	32.23
15	62.73	47.55
16	33.25	54.39
17	37.50	36.65
18	27.76	43.20
19	17.08	4.17
20	32.66	60.49
21	54.57	43.07
22	25.02	78.63
23	29.80	43.65
24	26.57	73.62
25	24.77	72.61
26	25.51	83.68
27	23.78	85.65
28	26.38	80.26
29	37.64	64.39
30	25.81	81.50

mechanical efficiency, only recorded at 62.73%, since head losses also contributed to the obtained efficiency result. It was found that mechanical efficiency and discharge efficiency shared a direct relationship with each other. The higher the mechanical efficiency, the higher the discharge efficiency was achieved.

Moreover, the mechanical efficiency and the discharge efficiency are plotted in Fig. 11. The trendline shows that the majority of mechanical efficiency has

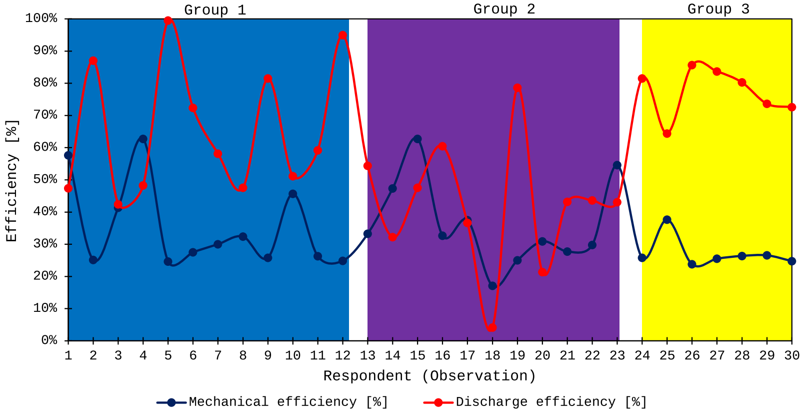

FIG. 11. Mechanical efficiency and discharge efficiency.

lower results as compared to discharge efficiency. NAM *et al.* [46] highlighted that the power take-off of manually operated pumps had lower energy conversion efficiency than motored power mechanical pumps. This had correlated to the mechanical efficiency of the newly developed pedal-operated reciprocating water pump, which had achieved lower results than the discharge efficiency due to losses from pipe friction and pipe fittings.

This result suggests that the water pumping system still inherently incurs losses, leading to lower mechanical efficiency compared to discharge efficiency. Among the three groups, group 1 of ages 13 to 21 demonstrated superior mechanical and discharge efficiencies, likely due to their greater physical activity and stamina during operation compared to the mid- and senior brackets. However, the discrepancy between hydraulic and discharge efficiency may have arisen from the complexity of the water pumping system, including factors such as internal leakage, and cycling techniques used by the user. This implies that head losses and respondents pedal operation play a crucial role in determining the overall efficiency, thus greatly affecting the overall performance of the water pumping system.

3.3. Relationships between the considered variables

In the regression analysis for the first variation considered, the age versus cycling speed variables, the computed p-value of 0.317705 was greater than the set significant level ($\alpha = 0.05$). For the second variation, the weight versus cycling speed variables, the computed p-value of 0.51548 was greater than the set significant level ($\alpha = 0.05$). For the third variation, the height versus cycling speed variables, the computed p-value of 0.56639 was greater than the set significant level ($\alpha = 0.05$). Lastly, in the last variation of the cycling speed versus burned calories variables, the p-value of 0.43934 was still greater than the set significant value of ($\alpha = 0.05$). Hence, all the computed p-values were greater than the set significant level, and this study came to a decision to accept all null hypotheses.

This signified that age, weight, and height had no relationship to the cycling speed of the respondents, and the cycling speed had no relationship to the burned calories of the respondents. This clearly confirmed that the parameters mentioned in the study of Phillips and Hopkins [30] had no significant effect on the proposed design because this study already addressed the gap of comfortability by developing a newly pedal-operated reciprocating water pump with less effort exerted by the users with high-efficiency outputs.

Furthermore, the level of relationship between age, weight, and height versus the cycling speed produced by the respondents was determined using linear regression and correlation analysis. This analysis measured the strength of the relationship between the considered variables. A similar analysis was also carried out to determine the level of relationships and provide insights into the factors that influence the cycling speed and the obtained burned calories of the respondents.

Figure 12 illustrates the linearity of the variables considered in this study. It is found that the plotted data are scattered along the trend line, and the linear trend line is almost in a horizontal position. This indicates that all the considered

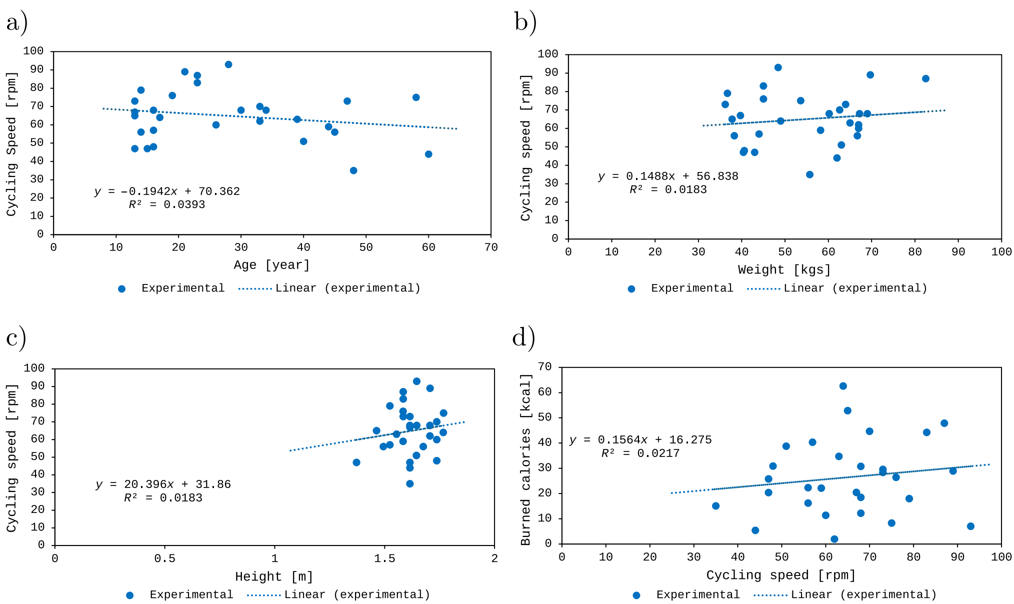

Fig. 12. Variation of variables: a) age versus cycling speed, b) weight versus cycling speed, c) height versus cycling speed, d) cycling speed versus burned calories.

variations have a very weak level of correlation since the obtained R^2 values are 3.93%, 1.83%, 1.83%, and 2.17%. From an engineering standpoint, the obtained percentages demonstrate very low effects, which can be interpreted as negligible results. Both analyses in correlation and regression have similar interpretations that the considered variables were not factors that could provide a significant impact on the obtained results. Thus, this indicated that age, weight, height, and cycling speed further confirmed that they did not affect the comfortability of the respondents when consequently operating the newly developed pedal-operated reciprocating pump.

4. Conclusion and recommendations

The study found that the reciprocating piston pump was an excellent design for modifying the newly developed pedal-operated water pump. When using this water pump, the user can only exert low levels of burned calories, as low as 1.98 kcal, which means that the pedal-operated pump can be used comfortably. This pump also achieved high mechanical efficiency, reaching up to 62.73%. Similarly, the discharge efficiency also reached up to 99.50%. In addition, the modified design for the seating system could accommodate various demographic populations, including children and the elderly. Therefore, the newly developed hydraulic pedal-operated water pump can be conveniently operated, which provides good efficiency outputs regardless of age, weight, and height of the user, unlike many other traditional manually operated pumps that require a tremendous amount of physical effort to work effectively and achieve the desired discharge output adequately.

Furthermore, to determine the level of comfortability when operating the newly developed pedal-operated water pump, it was found that age, weight, and height provided very low correlation levels of 3.93%, 1.83%, and 1.83% to the cycling speed of the respondents, respectively. On the other hand, the cycling speed also provided a low correlation level of 2.17% with the burned calories of the respondents. These findings further addressed the gap of comfortability, in which, from an engineering point of view, the percentage results interpreted that the cycling speed of the respondents provided a very low contribution to the burned calories. Hence, users from different age brackets only exerted just enough effort to power the pump and provide an adequate discharge water output.

Lastly, this water pump paved the way for providing sustainable alternative water pumps to communities that fell vulnerable to the unsophisticated and unequal water distribution facilities in the Philippines since it can supply water up to 40.46 L/min. Overall, this study might serve as a catalyst for the affected communities living in rural areas with limited water facilities who experience water scarcity and shortages, wherein they can construct this water pump for domestic usage and agricultural farming water supply.

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