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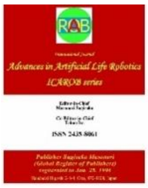

Research Article

Development of Pedal Powered Water Purifier System

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ABSTRACT

One of the major concerns in rural area is the struggle to get clean drinking water. This is because they are not supplied with clean water and thus must source for water from rivers, rainwater, and wells which are often contaminated and unsafe for drinking. The objective of this study is to design and fabricate a functional prototype of a pedal powered water purifier, and to ensure that purified water is safe for consumption based on chemical water analysis. A structural analysis via Finite Element Analysis (FEA) simulation is performed on the prototype. Then, the quality of the purified water is compared to the Drinking Water Guidelines (DWG) provided by the World Health Organization (WHO). The system utilizes the distillation method to produce clean drinking water. The charging efficiency of the generator has reached 48.74% at 60rpm cadence. The outcome from FEA results showed that the structure of the supporting frame can withstand up to three times the normal load. In addition, based on the chemical analysis of purified water, it has been proven that it meets the standards set by WHO and is safe for consumption.

1. Introduction

Clean water supply is often unavailable in certain rural areas. This poses a huge challenge to the people living in rural areas, as they would have to obtain water from rivers or rainwater. These water sources are often polluted due to human activities such as open burning, improper disposal of garbage and industrial waste. If the water is not treated properly before consumption, the consumers are in high risk of being infected by diseases or poisoned.

There are several methods to purify water such as boiling, distilling and reverse osmosis. However, distillation is one of the most reliable methods of water purification [1]. The distillation process is able remove contaminants such as microorganisms, dissolved substances, and suspended substances, thus resulting in a very pure water. To verify if the purified water is safe for consumption, it is necessary to conduct chemical water analysis on the purified water, and then comparing the results to the World Health Organization (WHO) Drinking Water Guideline. The parameters to be measured as indicated in the drinking water guideline are chemical properties, bacteriological properties and physical properties of the water [2].

Distillation is a process which consists of evaporation and condensation. Heat energy is required in distillation to allow the water to evaporate. Traditionally, heat is obtained by combustion of fuel, which is harmful to the environment as it produces greenhouse gases that contributes to global warming. Therefore, electrical energy is a better alternative to produce heat energy. Electricity can be generated in several methods. Pedal power generation is the method used in this research that works on the principle of conservation of energy, as kinetic energy from pedalling motion is converted into electrical energy. According to researchers, they have

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found that the most efficient cadence is 60 rpm as it has the lowest metabolic cost [3]. Functional threshold power (FTP) is the maximum average power a cyclist can sustain within one-hour period. Experiments have been done and it shows that average cyclists have an average FTP of 210.6W [4]. In addition, there are torque variations of over 90% and speed variations of about 5% in a single crank revolution [5]. These data are crucial while designing a pedal powered generator.

2. Overview of System

The proposed system is to work on the principle of conservation of energy, whereby energy is converted from one form to another. The basic working principle of the system is shown in Fig. 1. When the user pedals, the kinetic energy is transferred from the crank to the chain, and then to the sprocket of the generator. Then, mechanical energy produced by pedalling is converted to electrical energy with the generator, and the electrical energy will be stored in a battery. The electrical energy stored will then be used as per the need of the user to operate a water heating element for water heating and distillation. During the distillation process, the water will first be boiled, and the steam produced will be channelled through a copper tube to allow for condensation. Finally, pure water will be produced from the condensed water.

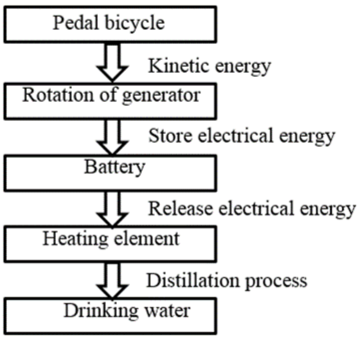

Fig. 1. Flow chart of working principle of system.

3. Fabricated Prototype

A prototype has been fabricated to conduct the experiments, and the components of the prototype are labelled in Fig. 2. and listed in Table 1.

Fig. 2. Full components of prototype.

Table 1. List of prototype components

No.	Component	Specifications
1	Bicycle	N/A
2	Supporting frame	N/A
3	Generator	36V, 250W, 3000rpm
4	Multimeter	N/A
5	Battery	12V, 8Ah
6	Charge controller	12V DC to 36V DC
7	Heating container	N/A
8	Cooling container	N/A
9	Collection container	N/A

3.1. *Distillation unit*

In the distillation unit, a heating container, cooling container and collection container are shown in Fig. 3. In the heating container, a heater is immersed to boil and evaporate the water. Then, the steam will pass through a copper tube having a water jacket to allow for a higher condensation rate. The condensed steam is converted now to pure water.

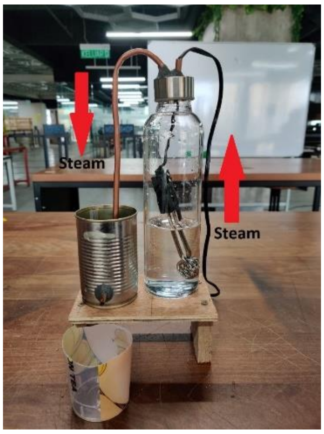

Fig. 3. Distillation unit.

3.2. ***Structural analysis***

The supporting frame of this system plays an important role in supporting the weight of the system. Therefore, the material used must be strong to prevent the system from collapsing while in operation. AISI type 304 stainless steel has been chosen for the supporting frame material due to its high shear modulus value, good corrosion resistance and low-density requirement. Material with high shear value has higher resistance to deformation when force is applied to the structure. Good corrosion resistance indicates that the material is suitable for outdoor usage. Meanwhile, low density requirement for the material means that the supporting frame's weight is low. Thus, in the case where the user wants to relocate the system, it would be easier to carry the supporting frame.

In this project, the support frame of the system has been used to lift up the rear portion of the bicycle. Therefore, the support frame has to support the weight of the user and the bicycle. ANSYS engineering simulation software has been used in the design process of the support frame to perform finite element method analysis. Finite element method (FEM) is one of the common methods applied in engineering design to analyze and solve the problems that include the area of interest in heat transfer, electromagnetic potential, mass transport, structural analysis and fluid flow in a numerical way. Boundary conditions and key parameters are important settings that are required in providing an accurate analytical solution and results in system of algebraic equations which formulated from the method. Finite element analysis (FEA) is the analysis and study of a phenomenon with FEM.

Simulation is an important technique used in engineering design. It is applied to observe and analyze the effects of several factors such as load, pressure, temperature and etc. on the performance and behavior of the designs. Moreover, it can predict the failure of designs due to certain limit of force or under any critical condition and prevent any tragedy or accidents from happening. It is the most cost saving and safe methods in evaluating the safety and quality of a design as it a non-destructive method.

In this simulation, different parameters such as point mass, remote point and fixed support have been set on different parts of the design based on different conditions. The simulation results obtained are focused on total deformation, equivalent stress (Von Mises) and factor of safety.

Remote point is defined as the point of application of force and load on a structure. In this simulation, there are two remote points, which resembles the area where the frame of the bicycle is connected to the shaft. The remote points are shown in Fig. 4.

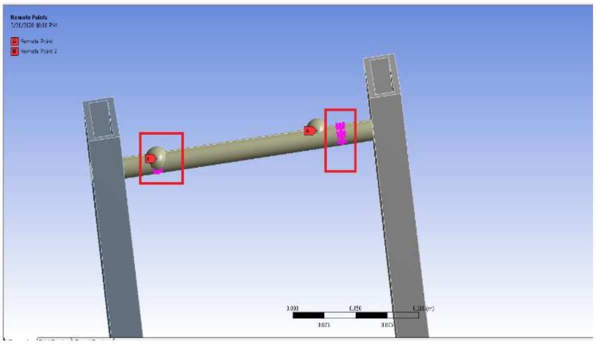

Fig. 4. Remote points applied onto the shaft.

According to a past research, the average weight of Malaysian males is 68.4 kg and the average weight of Malaysian females is 58.7 kg [6]. Therefore, the point mass applied onto the shaft is 40 kg on each side, which totals up to 80 kg. The weight of the user and bicycle is considered in the total mass applied onto the shaft. The mesh size applied is 5mm and the fixed support is defined at the bottom of the structure, as it is in contact with the ground. Fig. 5 shows the location of fixed support of the structure which is highlighted in blue.

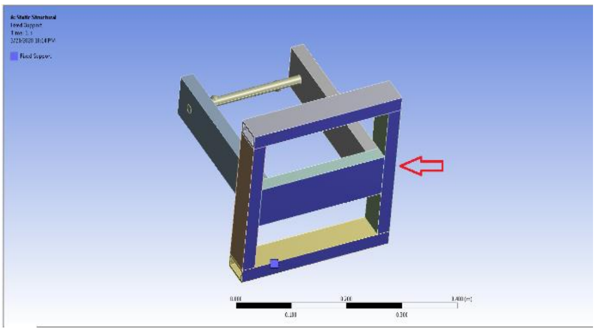

Fig. 5. Fixed support of the structure.

The results of simulation on the support in equivalent stress, total deformation and factor of safety are shown in Fig. 6, 7 and 8 respectively.

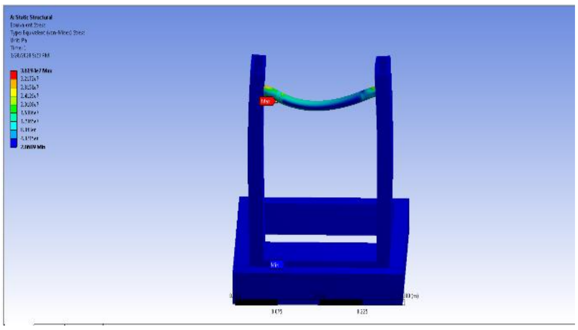

Fig. 6. Total equivalent stress of support frame.

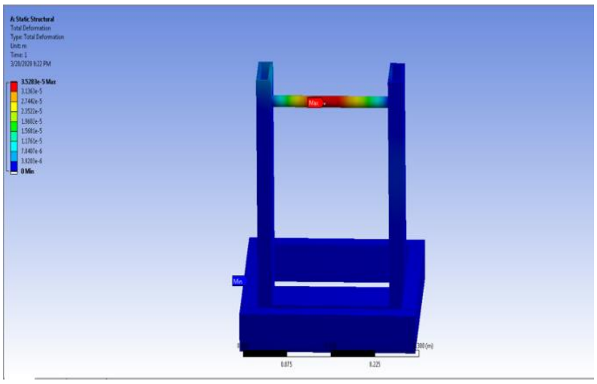

Fig. 7. Total deformation of support frame.

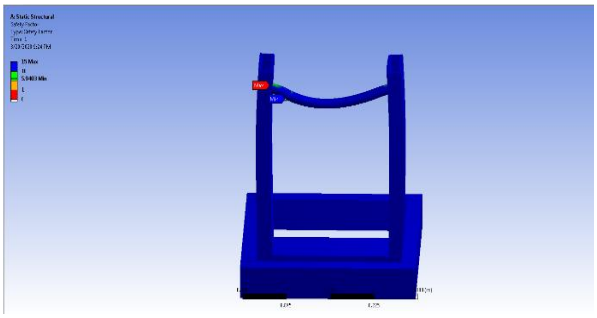

Fig. 8. Safety factor of support frame.

Based on the results obtained, the highest stress is focused on the area of point mass application at a value of 3.62 x 107 Pa. This value is lower than the yield shear strength of the AISI 304 stainless steel material of the shaft at 124.7 MPa. The total deformation is from a range of 0 to 3.53 x 10-5 m, with the maximum deformation at the center of the shaft. This scenario happened because the center of the shaft is located the furthest away from the supports. Furthermore, the maximum deformation is very low at 3.53 x 10-5 m, which is not visible to the naked eye and is strong enough to support the weight of the system. The safety factor of the system is from 5.94 to 15. This means that the structure is capable of supporting up to 5.94 times the design load.

In order to further determine the structural strength limit of the supporting frame, the load applied to the shaft is increased by three times. The point mass applied on each side of the shaft is 120kg. The results of simulation on the support in equivalent stress, total deformation and factor of safety are shown in Fig. 9, 10 and 11 respectively.

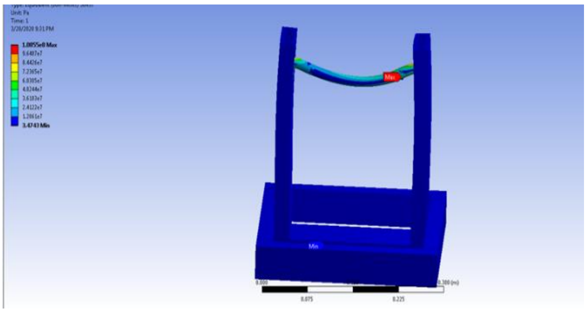

Fig. 9. Total equivalent stress of support frame.

Table 2. Data collected during efficiency test of generator.

N_{pedal} (rpm)	N_{gen} (rpm)	Current (A)	Voltage (V)	Energy Output (Wh)	Energy Input (kcal)	Energy Input (Wh)	Efficiency (%)
30	1563.82	3.62	12.83	36.00	93.00	108.09	33.31
40	2085.10	4.88	12.90	49.70	107.00	124.36	39.96
50	2606.37	6.91	13.07	74.40	119.00	170.49	43.64
60	3127.64	7.84	13.22	89.50	158.00	183.63	48.74
70	3648.92	8.32	13.36	95.80	179.00	208.04	46.05

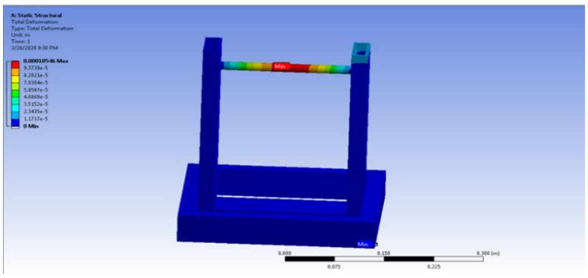

Fig. 10. Total deformation of support frame.

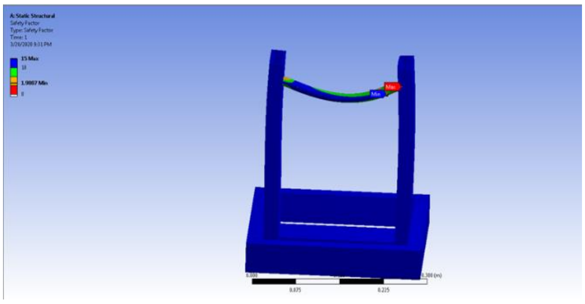

Fig. 11. Safety factor of support frame.

Based on the results obtained, the total equivalent stress is from 3.47 Pa to 1.09 x 108 Pa with a total load of 240kg applied. The total deformation of the structure is from 0 to 0.0001m. The safety factor is from 1.98 to 15. These results prove that the structure is strong enough to support even at triple the amount of intended load as the deformation is little and the value of safety factor is larger than 1.

3.3. *Energy analysis*

The system has been tested to verify the efficiency of the generator. The equipment used in the test are Garmin Edge 1030, Garmin Heart Rate Monitor and Garmin Cadence Sensor to determine the RPM of the crank and heart rate of the user. The data collected by the sensors are used by the bike computer. Garmin Edge 1030 has been used to calculate the energy exerted according to the manufacturer's algorithm. A multimeter has been used to measure the current and voltage output from the generator. The energy output over the duration of the tests have been measured by the multimeter. The tests have been conducted for 10 minutes duration for each of the RPM at crank. The data recorded is shown in Table 2.

The generator used is having an internal gearbox with a gear ratio of 9.78:1, and the gear ratio of the generator's sprocket with the crank gear is 5.33:1. Therefore, the rotational speed of generator has been calculated with Eq. (1). Whereby N_{gen} is the rotational speed of generator, N_{pedal} is the rotational speed of pedal or cadence.

$$N_{gen} = N_{pedal} \times 5.33 \times 9.78 \quad (1)$$

Based on the data collected, the relation between cadence and efficiency of the generator is plotted and illustrated in Fig. 12. Also, the relation between cadence and voltage is illustrated in Fig. 13, and the relation between cadence and current is illustrated in Fig. 14.

According to Fig. 12, it is shown that the relationship between cadence and efficiency of generator is linearly proportional from 30 rpm until 60 rpm. This is because the selected generator has a rated peak output at 3000 rpm. Therefore, as the cadence reaches 60 rpm, the generator will be rotating at 3129.6 rpm. Furthermore, it also corresponds to the research done by Brennan et.al [3], whereby the cadence of highest efficiency is at 60 rpm.

At 70 rpm, the efficiency drops as compared to 60 rpm. This is because the metabolic cost to maintain cadence at 70 rpm is higher, therefore consuming more energy from the user.

Fig. 13. and Fig. 14. are showing that as the cadence increase, the voltage and current output increase. This characteristic is expected as permanent magnet DC generators are supposed to have a linear relationship between revolution speed and current, and linear relationship between revolution speed and voltage [7].

The range of calculated efficiency for the generator is ranging from 33.31% to 46.05%. The used battery of 8 Ah capacity could be fully charged in around 57 minutes with charging current of 8.32 A. The fully charged battery can support the system for around 46 minutes, and to boil 2.265 Litres of water and make it ready for drinking.

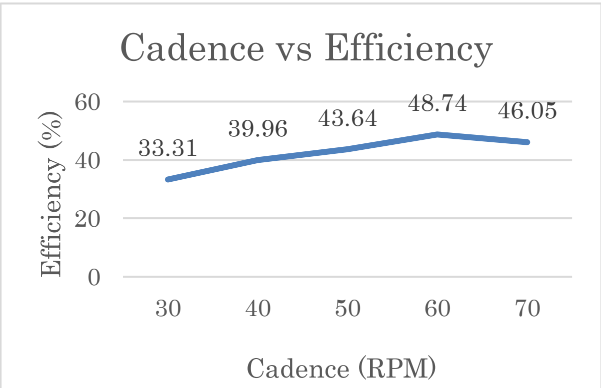

Fig. 12. Relationship between cadence and efficiency of generator.

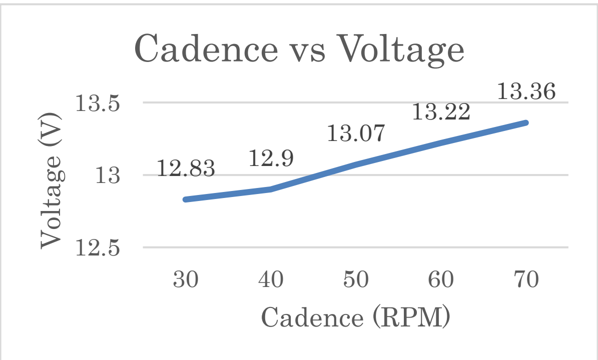

Fig. 13. Relationship between cadence and voltage.

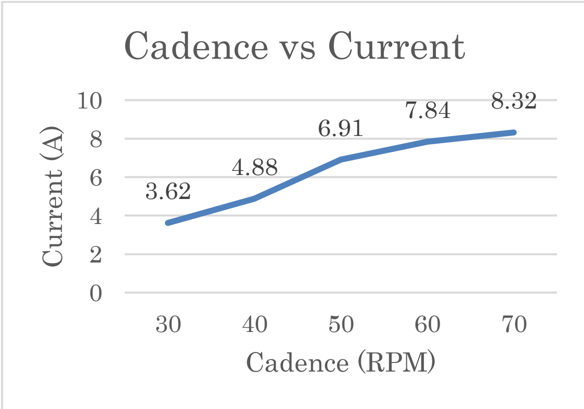

Fig. 14. Relationship between cadence and current

Efficiency Comparison

The efficiency of the system fabricated in the current study has been compared to the references to verify the results obtained. The efficiency comparison is shown in Fig. 15. The efficiency calculated for the current system is 48.74% , whether the system studied by Anyanwu [8] has higher efficiency and this can be attributed to the lesser electrical losses as it has lesser electrical components. For instance, a charge controller has been used in the prototype of the current study to regulate the voltage input into the battery. The charge controller has to step down the generator output voltage from 36V to 24V as required by the battery for charging. In comparison, a 24V generator has been used in Anyanwu’s system and the voltage is not regulated. In the process of stepping down the voltage, some of the electrical energy is wasted as heat energy released into the surrounding, resulting in lower overall efficiency.

The efficiency of the system produced by Zaman [9] is also higher than the current system. The system developed by Goguely [10] has a lower efficiency compared to the current study. It uses a belt drive to transmit force from the rear wheel of the bicycle to the generator. In this case, the slippage is higher as compared to the chain drive utilized in the current system. Furthermore, an automotive alternator has been utilized, which is separately excited and draws power from the battery to produce electromagnetic field. On the other hand, this study has used a permanent magnet generator, which is self-excited and does not require an external power source for field excitation, thus the higher efficiency.

In conclusion, the results that has been obtained in this study can be considered valid in comparison with the other studies.

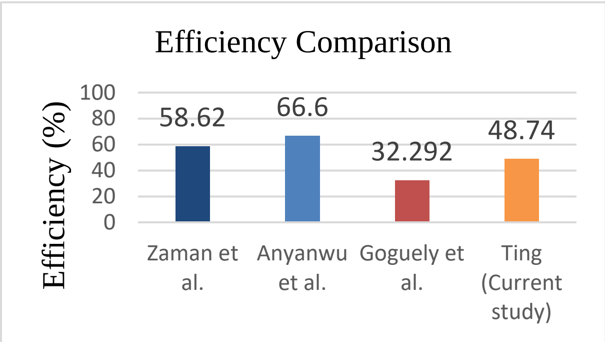

Fig. 15. Efficiency comparison of author to references

3.4. *Water Analysis*

The samples that have been used in this experiment is rain water, stream water, tap water and saline water. The rainwater and tap water have been self-collected at a residential area in Kuala Lumpur, Malaysia. The stream water has been collected from a country side located in Negeri Sembilan, Malaysia. The saline water has been self-made by adding salt to tap water. The content of water before and after purification is shown in Table 3. Based on the results obtained in Table 3, The TDS and EC of each purified samples are different from each other. This is because they are taken from different sources and thus have different level of contamination initially. It can be observed that the TDS and EC are reduced for all the samples, which means that the contaminants in the water have been removed. In addition, the pH level of all the samples is closer to pH 7, which indicates a purer water. It is shown that all 4 samples of water after purification meets the requirement of WHO Drinking Water Standards. Therefore, the purified water is safe for drinking purposes.

Table 3. Contents of water before and after purification.

Parameters	Source of water								WHO Standards
	Rain water		Stream water		Tap water		Saline water		
	Before	After	Before	After	Before	After	Before	After	
TDS (ppm)	66	15	32	10	63	13	5130	32	1500
EC (μS/cm)	132	46	64	21	126	38	10260	68	2500
pH	7.17	7.09	7.65	7.16	7.34	7.12	8.83	7.20	6.5-8.5

4. Conclusion

The objective of the study has been achieved, which is the design and fabrication of the pedal powered water purifier which has been successfully fabricated and tested. The structural integrity of the system was verified and tested according to the boundary conditions applied. Based on the simulation results, the structure of the system is safe as the stress and load applied onto it is lower than the material's strength. Furthermore, the system is also tested by applying a load of three times the intended load, and the results was satisfactory as it was able to support the load.

Based on the comparison of results obtained with the references, the efficiency of the generator has been calculated and found that it can reach 48.74% with 60 rpm of the crank. The other achieved objective is ensuring that the purified water is safe for human consumption, as chemical water analysis are conducted. According to the results obtained from the water analysis, all the parameters tested are within the requirement of WHO Drinking Water Guidelines. Therefore, the produced water is safe for human consumption.

Acknowledgement

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Authors Introduction

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