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Discharge performance of solar-powered sprayer

Raymundo V. Romero[1], Nelson V. Romero[1]
[1]*College of Engineering and Technology, Partido State University, Philippines*

Abstract: The solar-powered sprayer was built to analyze the fluid discharge performance with and without using of the storage battery. The device was evaluated in terms of weight and cost. The fluid discharging capacity was described utilizing the sprayer 1SMF or MF9-B and without storage battery. The construction was based on Bernoulli's principle and the presented operation diagram. The device was tested on sunny, cloudy and partially cloud covered days. Fuzzy logic was used to estimate the amount of fluid discharged at a certain percentsge that the atmosphere was partially covered with clouds. The solar sprayer with no storge battery was found functional during sunny days and from 0 to 50% cloud cover. It was found inefficient and non-functional beyond 50% cloud cover and during rainy days. Larger storage battery if installed in the solar sprayer delivers high cost. The contribution of weight and cost to the structure are directly proportional. However, the capacity of discharging fluid that the battery contributes is lower than using a solar panel only as source of power.
Keywords: Solar sprayer, discharge, fuzzy logic, Bernoulli's principle, solar energy

I. INTRODUCTION

Field spraying is an essential task in agriculture as it improves crop growth. Manually operated spray pumps are the most common but cause fatigue to workers and can't be used for a longer time. Replacing the conventional sprayer into solar-powered is possible as solar energy is widely available at free cost [1]. There are solar-powered sprayers that had been developed at higher output, with lower energy consumption and discomfort. That is by embedding electronic controller protection against deep discharge and overcharging of battery for longer operational life [2]. However, the operation is more economical due to lower operation maintenance resulting in less environmental impact than those powered by the internal combustion engines [3]. Some devices are backpack made of the photovoltaic panels making the operator in movement with the sprayer in static [4]. The usually added components are the solar panel, battery, motor, and the spinning disc nozzle [5]. The device may be used for domestic purposes such as for washing of vehicles [6]. Maintenance is simple that farmers can do the spraying themselves to increase output efficiency [7], [8].The usual size of the photovoltaic system is directly dependent on the size of the pump, the amount of the required water, and availability of solar irradiance [9] while others [10] were embedded with a three-wheeled vehicle to spray with little human assistance. Many researchers had engaged to conduct studies about solar sprayer. Their outputs were found to be friendly to users and the environment, easy to operate, uses renewable energy, and efficient. However, all of them are using battery and electronic controllers. This study was conducted to establish the discharge performance of solar-powered sprayers in case that using the battery and charge controller is disregarded in operating the equipment.

This was aimed to build a solar-powered sprayer that may facilitate works related to industry and agriculture. This analyzed the capacity of discharging fluid concerning weight, cost, using 1SMF or MF9-B storage battery, and with no battery.

II. METHODOLOGY

The construction of the solar sprayer was guided by Bernoulli's principle. This states that in the same fluid, the velocity is large and the pressure is small [11]. The equation of Bernoulli's theorem in Figure 1 is:

$$\left(P_a + \frac{1}{2}\rho V_a{}^2 + \rho g h_a\right)Q + P_u = \left(P_b + \frac{1}{2}\rho V_b{}^2 + \rho g h_b\right)Q \quad (1)$$

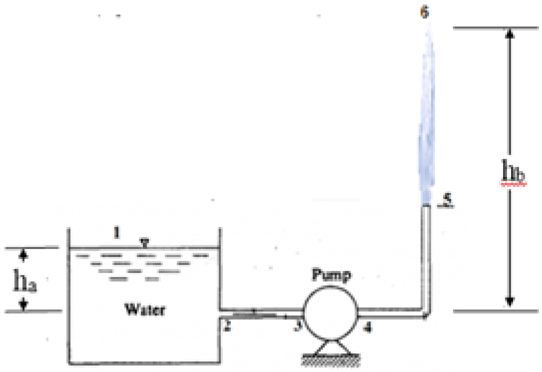

Fig. 1. Diagram of Bernoulli's principle

Where 1 is the surface which is higher ($h_{a)}$ from the pump, 2 is the exit of water from the tank, 3 is the entrance and 4 is the exit of water from the pump, 5 is the nozzle and 6 is the tip of the water spray which is higher ($h_{b)}$ from the pump. P_a is the water pressure at ha from the pump. P_b is the water pressure at hb higher from the tank, ρ is the molecular density of the gas, g is the specific gravity of water and P_u is the power output of the pump to displace the water.

2.1 Operation diagram

The operation of the solar sprayer follows the diagram shown in Figure 2. This is composed of the following main parts: solar panel, trigger switch, pump, piping, and nozzle. Unlike other solar sprayers, this does not have other components like storage battery and charge controller. The sprayer is intended for use in an open field during the daytime that the storing of electricity is not needed. Utilizing a storage battery is an additional cost and weight which is an encumbrance on carrying the equipment.

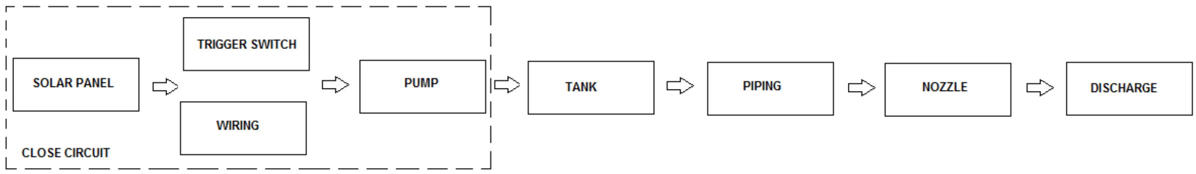

Fig. 2. Operation Diagram

The diagram shows that the sprayer contains solar-panel. It is the main source of power with a capacity of 50 watts. The solar panel is connected by wiring to a motor pump to form a close circuit. The circuit is controlled by a trigger switch. The purpose of the motor pump is to apply pressure on the fluid inside the tank and convey it to the nozzle. The DC motor pump is 12 volts, 2.2 A, and 60 watts. It is connected to the piping which acts as the passages of pressurizedfluid to be conveyed to the nozzle. The nozzle which is adjustable is used to regulate the discharged fluid to form a fine spray.

2.2 Other components

Parts of the sprayer (see figure 3) are the handcart and the strings. The handcart was included to facilitate the transport process of the sprayer. A fully loaded sprayer will contribute enough weigh in transporting the equipment. The string was used to make the sprayer and solar panel intact and be carried together using a handcart.

2.3 Measurement of discharge

The discharge of liquid was determined by getting the time that a one-liter container was filled with water as the water pump starts working in the sprayer. The discharge was then computed using the equation below.

$$Q = \frac{V}{t} \qquad (2)$$

Where Q is the discharge with a unit of a liter per second (L/s), V is the volume of the container in a liter (L) and t is the time in second (s).

2.4 Measurement of cloud cover

Measurement of cloud cover was done by taking a photogrammetric shot in the atmosphere. The percentage quantity was computed using image analysis.

2.5Discharge and cloud cover

The relationship between discharge and cloud cover was described using fuzzy logic analysis. Fuzzy logic is a reasoning that describes fuzziness transforming characteristic function to membership function to define the degree of truth [12] and that Fuzzy set Ã with full membership function in the set of the region on the universe may consist of all elements of y on the universe of information as:

$$\mu_{\tilde{A}}(y) = 1 \qquad (3)$$

However, if characterized by a nonzero membership in the set, may consist of all those elements *y* on the universe of information as:

$$\mu_{\tilde{A}}(y) > 0 \qquad (4)$$

If characterized by a nonzero but incomplete membership in the set may consist of all those elements y of the universe of information as:

$$1 > \mu_{\tilde{A}}(y) > 0 \qquad (5)$$

Fuzzification was then used to transform a crisp set to a fuzzy set or a fuzzy set to a fuzzier set which translates accurate input crisp value into linguistic variables. Defuzzification was applied to reduce fuzzy set into the crisp set using the centroid method with defuzzified output Ẍ which is expressed by the equation:

Fig. 3. The image of the solar powered sprayer

$$\bar{x}^{\cdot} = \frac{\int \mu_{\tilde{A}}(x)\,.\,xdx}{\int \mu_{\tilde{A}}(x)\,.\,dx} \qquad (6)$$

The diagram of estimating the discharge with a computed percentage of cloud cover is shown in Figure 4.

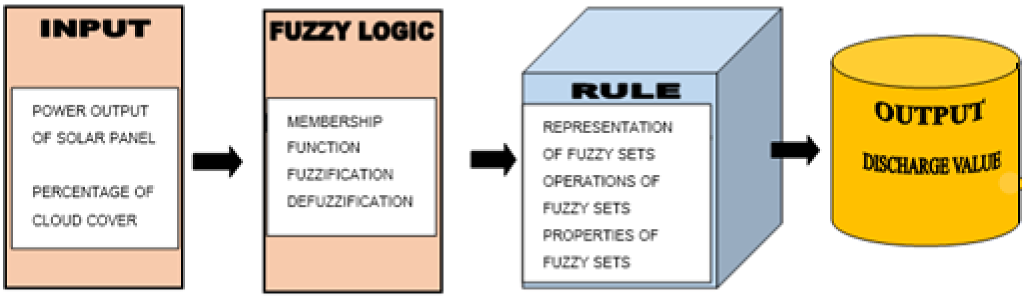

Fig. 4. Diagram of estimating the discharge value at a certain percentage of cloud cover using fuzzy logic

The input data are the power output of the solar panel and the percentage of cloud cover. Fuzzy logic included the steps such as determining of membership function, fuzzification, and defuzzification with the following rules applied: representation, operation, and properties of fuzzy sets. The output was the discharge value.

III. RESULTS AND ANALYSIS

3.1 Weight of the materials

Considered in the design of the equipment is safety and economy. Humans as part of a system must be fully integrated safely and efficiently at the design stage [13]. Hence, the designed equipment was computed to be at lightweight since lifting an expectedly heavy object may be a major risk factor for low back pain which will eventually lead to an increase in muscle activation, the stretch of ligaments, posterior disc, and loss of balance [14]. Work settings that involve pushing and pulling may be checked for potential improvements with regards to the lower weight of the loaded handling device [15]. Table 1 shows the component materials of the sprayer and the corresponding weight.

TABLE 1. The component materials and the corresponding weight

Materials	Weight (kg)	Additional weight with charge controller and 1SMB battery (kg)		Additional weight with charge controller and MF9-B battery (kg)	
Solar panel	4.80	15.2	Percentage of increase (%)	3.0	Percentage of increase (%)
String	0.20				
Piping	0.20				
Full liquid tank	28.00				
Cart	2.20				
Pump assembly	0.40				
Nozzle and handle	0.30				
Total	36.10	51.30	42.10	39.1	8.31

The total weight of the sprayer is 36.10 kg, however, it will increase if a storage battery will be added. Adding a charge controller and 1SMF battery will increase the weight by 42.10% or additional weight of 15.20 kg. If a smaller battery MF9-B is added will increase the weight by 8.31% or additional weight of 3.0 kg. It was assumed that the sprayer which is usually used during the daytime will function through the power supplied by the solar panel. The exclusion of battery in the design was considered to produce lightweight equipment that could be carried easily while performing spraying activity from one place to another [16].

3.2 Cost of materials

The total material cost of PHP 4880.00 is sufficient to make the solar sprayer function. However, the material cost will increase by 122.95% or an amount of PHP 6,000.00 if a charge controller and 1SMF storage battery shall be added. The material cost will increase by 45.08% or an amount of PHP 2,200.00 if a charge controller and smaller battery MF9-B storage battery are added.

TABLE 2. The material and additional cost considering the charge controller and storage battery

Materials	Cost (PHP)	Additional cost with charge controller and 1SMB battery (PHP)		Additional cost with charge controller and MF9-B battery (kg)	
Solar panel	2,000.00	6,000.00	Percentage of increase (%)	2,200.00	Percentage of increase (%)
String	60.00				
Piping	70.00				
liquid tank	250.00				
Cart	420.00				
Motor Pump	1600.00				
Nozzle and handle	480.00				
Total	4880.00	10,880.00	122.95	7,080.00	45.08

The two options of adding either a smaller or larger storage battery make the cost of the solar sprayer very expensive. In this study, the total equipment cost is minimized by developing an optimal and investigative process for the problem of designing a flexible assembly line when several alternatives are available [17].

3.3 Discharge performance of the solar sprayer using storage batteries

Sunny weather makes the solar panel operates efficiently the whole day but is opposite during cloudy days. Cloud cover has a great impact on photovoltaic solar performance that it decreased the daily energy yield of the solar panel [18]. The presented data on Table 3 shows that the solar sprayer without storage battery can function from 6:00 AM to 5:00 PM during partly cloudy days. The presented data were gathered not on the same days for the reason that during partly cloudy days there are times that the atmosphere is fully covered with clouds making the spray operation interrupted. The data revealed that the largest discharge was 0.015 liters per second while the lowest is 0.03 liters per second.

TABLE 3. Discharge performance of the solar sprayer powered directly from the sun, smaller battery and larger battery

Time	Mean Q (L/s)	Mean T (°C)	Mean Q (L/s) using 1SMF battery	Less %	Mean Q (L/s) using MF9-B battery	Less %
6:00-7:00	0.011	35	0.004	63.64	0.003	72.73
7:00-8:00	0.011	35				
8:00-9:00	0.015	45.5				
9:00-10:00	0.014	48				
10:00-11:00	0.014	49				
11:00-12:00	0.012	46.5				
12:00-1:00	0.011	44				
1:00-2:00	0.011	44				
2:00-3:00	0.003	48				
3:00-4:00	0.003	46.67				
4:00-5:00	0.010	38				
Mean	0.011	43.61				
Note: Discharge data were gathered not on the same day						

The data implies that the recorded fluid discharges using direct sunlight is varying from the lowest discharge of 0.003 L/s reaching up to 0.015 L/s and most of the recorded and mean discharge (mean Q = 0.011 L/s) are greater compared to that of using 1SMF battery (0.004L/s) and MF9-B (0.003 L/s) (See Figure 5). The data implies that the discharge is better using direct sunlight but is interrupted if the cloud cover in the atmosphere is excessive.

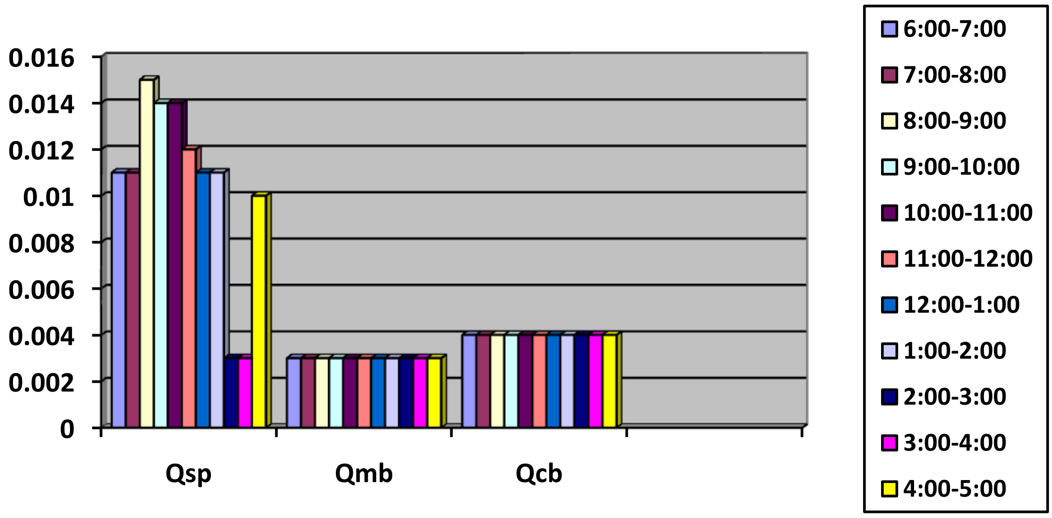

Fig. 5. Discharge performance of solar sprayer powered by the solar panel (Qsp), 1SMF battery (Qcb), and MF9-B battery (Qmb)

The data revealed that the outside temperature has no significant effect on the flow of discharging fluid. There are times that even with low temperatures the discharged liquid is greater than the time with higher temperature. The tendency of the open-circuit voltage to decrease and the reverse saturation current density to increase with increasing temperature in the solar cells results in a decrease in the efficiency with increasing temperature [19]. However, it is useful to understand the effect of temperature on the solar cell and module performance, to estimate their performance under various conditions and clarify that the short circuit current increases so monotonous with temperature and then saturates to a maximum value before decreasing at high temperatures [20].

3.4 Cloud cover and liquid discharges of the solar sprayer

Based on the previous thoughts, it is necessary to look into the cloud cover rather than the temperature in estimating the discharging performance of the solar sprayer. There is a strong relationship between output power and hourly cloud coverage variations [21] but clouds reduced the short circuit current (Isc) and maximum power output (Pmax) as well as the efficiency of the PV module [22].The performance of the sprayer without storage battery depends on the cloud cover. The estimated discharge on the sprayer based from the percentage of cloud cover in the atmosphere is shown in Table 4. It specifies that as the percentage of cloud cover is increasing the discharge performance will decrease. The data was determined by applying fuzzy logic analysis. The fuzzy rule-based system has proven to be effective in monitoring the efficiency and diagnosing the condition of PV panel [23].

TABLE 4. Cloud cover and discharge performance

Cloud Cover (%)	Discharge (L/s)
20	0.015
25	0.013
30	0.010
40	0.009
50	0.006
Mean	0.011

The table shows that at 20 percent cloud cover of the atmosphere performed the highest discharge of the sprayer while it is at 50 percent cloud cover that the slowest discharge was recorded. Beyond 50 percent cloud cover, the solar sprayer doesn't work anymore.

The liquid discharge of the sprayer using solar energy is highest compared to that of using 1SMF or MF9-B batteries implying that the sprayer performs better using solar panels as the source of energy (see Figure 4). The result demonstrated that a solar sprayer with no storage battery functions best in discharging liquid particles on sunny days and is opposite on cloudy days. However, if the atmosphere is partly covered with clouds the result of fuzzy analysis has established that it should be at less than 50% of cloud cover that the solar sprayer may perform efficiently while beyond of that value (50% - 100%) of cloud cover, the solar sprayer is inefficient.

3.5 Discharge, cost, and weight

The relationship between discharge, weight, and cost was analyzed. The result is presented in figure 6.

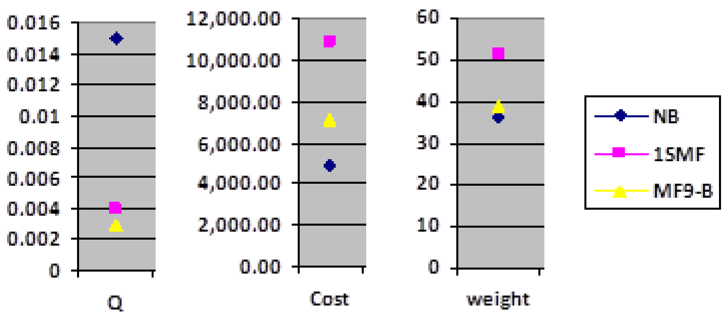

Fig. 6. Compared discharge, cost, and weight using the solar panel, 1SMF battery or MF9-B battery.

In terms of cost and weight, sprayer with no battery is the lowest. This implies that to construct a sprayer with no battery is achievable, functional, and cheaper. The complete application and exploitation of engineering advances require the revision of traditional agricultural machinery management process that in planning and management of equipment consider different parameters, including not only the cost but also their dimensions, weight, and the needed power. There is some expected high correlation between weight and tank capacity, which eventually play a key role and impact on the price formation and on the performance [24].

IV. CONCLUSION

The solar sprayer was constructed. With no battery it is functioning if the atmosphere is with cloud cover of not more than fifty percent, however the capacity is fluctuating. Larger storage battery if installed delivers higher cost which means that the contribution of weight and cost to the structure are directly proportional. However, the capacity of discharge that the battery contributes is lower than using the solar panel only as of the source of power.

V. RECOMMENDATION

Although, this study was able to establish the functionality of the solar sprayer without using storage battery, more studies may be conducted particularly on its application with more than fifty percent cloud cover in the atmosphere.

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