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DESIGN DEVELOPMENT AND PERFORMANCE EVALUATION OF SOLAR POWERED SPRAYER WITH WATER LEVEL INDICATOR

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ABSTRACT

Currently in Bangladesh farmers use hand operated sprayer or motorized sprayer in agricultural fields. Generally in the agricultural field, traditional or conventional techniques like shoulder mounted spraying system have been used because it is cheaper, easy to use and less costly. Continuous use of traditional energy resources will have high risk of rising in price and energy depletion. Now-a-days there is a great need for ''conservation of energy'' and application of renewable energy. This paper presents the design, development and evaluation of a solar powered spraying system. The specific objectives of this research is to design and fabricate the solar powered sprayer by considering parameters like desired spraying rate, low weight, low cost, faster coverage of area and high field efficiency. A two-nozzle sprayer was fabricated with MS bar frame and 4-wheel trolley with water level indicator which runs on power source as a DC battery (12 volt, 8.2 Ah) via solar panel and runs by a DC motor (12 volt, 2A). The entire unit is portable and is operated by one labor. The design mainly eliminates the shoulder mounting sprayer setup which causes back pain, uses of fossil power which is non-renewable and hazardous and extensive use of manpower. The machine was compared to conventional sprayer and found more efficient. Pump efficiency almost 83.33% found for single nozzle and 93.33% for double nozzle and the sprayer is 58% time saving than manual sprayer. The operating cost of the machine was 802 Tk ha^{-1}. Also found capital recovery factor, capital consumption and annual cost of the solar operated sprayer were 0.26, Tk 1520 and Tk 41665, respectively.

Keyword: Sprayer, water level indicator, machine performance, field efficiency, solar panel

INTRODUCTION

Modern Agricultural Mechanization is developing day by day. In present years, solar energy has given more attention for generating power, as a clean and renewable energy source. According to world energy report, we get around 80% of our energy from conventional fossil fuels like oil (36%), natural gas (21%) and coal (23%) (Krishnappa *et al.* 2017). Renewable energy can be utilized in many applications, like for lighting and heating in performing different agricultural devices. One of the most important agricultural devices is sprayer. Sprayer is the device which converts the mechanical energy into hydraulic energy. Spraying is the disposition of small amounts of water or liquid particles of effective size and distributing them uniformly over the surface area. Sprayer provides optimum utilization of pesticides, herbicides or any other liquid with minimum effort (Mishra *et al.* 2019). In a solar powered sprayer solar energy is first used to charge a storage battery and stored in the battery. Than the battery is used as power source to run the mechanical portion of the sprayer.Solar sprayer are very cost effective at the locations where spraying is required (Mukesh *et al.* 2018). The aim of this research work that the user need not carry the spraying instruments on his shoulders but just pull the mechanism mounted on the trolley to operate the pump and spray the pesticides. This makes the user feel comfortable, relaxed and less tiresome. The high pressure sprayers are often called as hydraulic sprayers (Siddharth *et al.* 2016). The sun powered cell contain semi-conductor material which utilize the photovoltaic impacts. At that point when the daylight is opposite to exterior of the PV sun powered board, could acquire higher efficient system. This research deals with efficient solar powered automated controlling spraying machine, to increase productivity of crops, to save time of farmers and avoid pollution problems. This machine would decrease the operational cost and decrease labor cost by using the advancing method. So solar powered spraying system can be a new concept to water on the horticultural crops, small plants and gardening purpose. The specific objectives were (i) to design and develop the solar powered hydraulic sprayer, record effective output voltage from solar panel and calculate efficiency of the sprayer and (ii) to measure the flow rate, pressure of the pump, evaluate the application rate on the field and study performance.

MATERIALS AND METHODS

The solar powered sprayer was made by locally available low cost materials procured from the local market. Frame structure of the sprayer was designed in AIE lab, HSTU, Dinajpur and fabricated in Shamim Engineering Workshop, Kalitola, Dinajpur.

Major components: The main components of solar powered hydraulic sprayer were used as follows: Solar panel, solar controller, DC battery, DC motor with pump, bucket with lid, hose pipe, trigger, lance, spray nozzle, pressure gauge, trolley wheel and water level indicator which is shown in Figure 1. Specification of solar power, solar controller, DC battery and DC motor with pump are shown in Table 1.

Table 1. Specifications of solar panel, solar controller, DC battery and DC motor with pump

Solar Panel	
Items	Specifications
Model	SL-29-36P
Dimensions (L×W×T)	50.8 cm×35 cm×1.8 cm
Rated maximum power (Pmax)	20.0 W
Voltage at maximum power (Vmp)	18.48 V
Current at maximum power (Imp)	1.08 A
Weight	2.78 kg
No. of cells	36
Solar controller	
Item	Specification
Brand	Infrastructure Development Company Limited
Dimensions (L×W×T)	14 cm×12.4 cm×2.3 cm
For analog	12.0 V 20.0 A
For digital	12.0 V 10.0 A
DC battery	
Item	Specification
Model	Power Guard 12.0V – 8.2Ah UPS Battery
Type	Rechargeable sealed lead acid battery
Voltage	12.0V DC
Rated Current	8.2 Ah
DC motor with pump	
Brand	Flopump (Mini diaphragm pump)
Model	FL-2203
Voltage	12.0V
Max. Current	2.0A
Max. Pressure	0.45Mpa
Discharge	3.0 lit/min

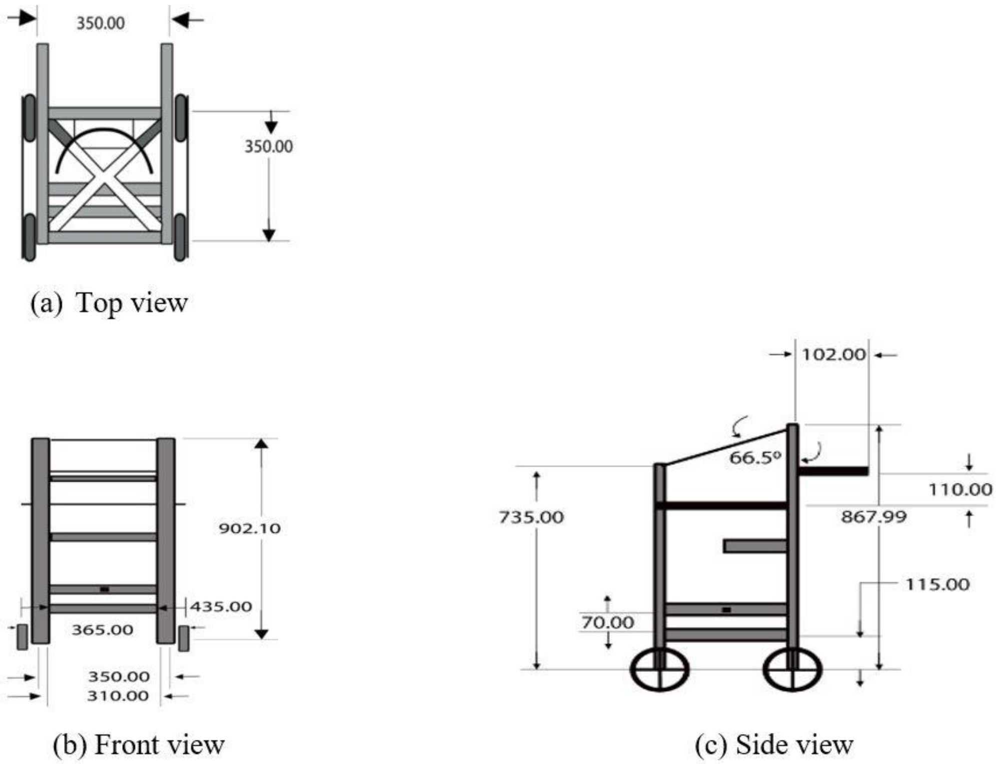

Figure 1. Design and development of the mainframe with dimensions (dimensions are in mm)

Fabrication of the machine: Solar panel was comprised of solar or PV cells made of semiconductor materials that convert sunlight directly into electricity. The solar panel mounted on the top and tilted to required angle 23.5^0 (Boxwell 2018) according to the manner of sunlight. The solar panel transmits current through the weir via controller and store charge in the DC battery. The acting of rotating motor could be controlled by sensor (i.e. water level indicator) attached with control unit (Figure 2). The frame was fabricated at the workshop. Each bolt was 8 mm diameter that was inserted to 4 holes by drilling mechanism. The same process was applied for 4 wheels. The plastic water tank was placed inside the frame for fixed in position- to weld half-circular additional support and placed on two cross-bar to its fixed position (Figure 1). For the battery, a stand was made with the help of paper sheet and enclosed by an angle bar, which attached with two screws. For solar panel was placed inclined on the top of the frame and fixed with the help four screw. The DC pump was placed on the bottom of the instrument with the help of four screws along with DC battery. For control unit namely as- IDCOL controller, two parallel consecutive bars was made on the frame to fix it with the help of four screw. A pipe was connected to storage tank with the help of connector to the pump. For the spraying purpose a spray gun was made with nozzle, which attached to a pressure gauge. The spray gun was connected to the hose pipe along with the pump, which discharged water. The sensor board was placed with the controller board to control mechanism of the instruments (Figure 3).

Figure 2. A photographic view of solar-powered sprayer

Experimental setup of solar powered hydraulic sprayer water level indicator:

(a) (b)

Figure 3. Experimental setup of (a) solar powered hydraulic sprayer and (b) water level indicator

Working principle: The arrangement was accomplished by the use of solar panel and a diaphragm pump which runs on DC supply attached to the solar panel. The solar panel generates DC power, its positive and negative charges were connected to a battery in order to store the power, and then use this power when the sun lights are not present. In this sprayer, we used water level indicator indicating how much water present in the storage tank. When we spray in the field, the pump running until the empty of storage water, this mechanism was controlled by arduino sensor. By conducting this device, we can spray pesticides also to the herbs, and other agricultural plants (Figure 4).

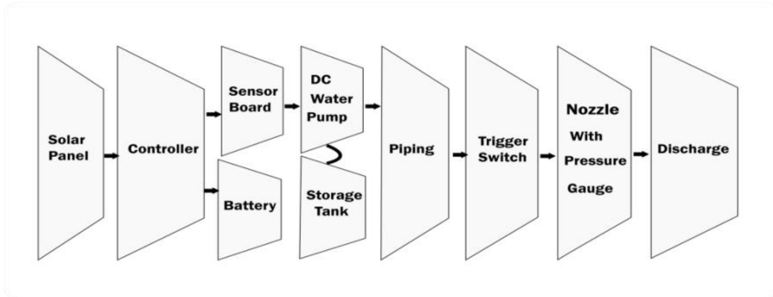

Figure 4. Flow chart of spraying system

Experimental site: The experiment was conducted in front of the Agricultural and Industrial Engineering (AIE) lab and backside of the central hospital also behind of guest house.

Technical evaluation

Charging time for battery: Charging time for battery was determined by using the following equation: $T_{(charge)} = \frac{R}{I}$ ....(1)

Where, $T_{(charge)}$ = Charging time for battery in hours, R = Battery rating in ampere hour, I = Total current transmitting by the solar panel in ampere

Discharging time while spraying: The discharging time while spraying in ideal condition was determined by the following equation (2):

$$T_{(discharge)} = \frac{R(ideal)}{I(pump)} \quad ....(2)$$

Where, $T_{(discharge)}$ = Discharging time for battery in ideal condition while spraying in hours, R(ideal) = Battery rating ideally in ampere hour, I(pump) = Total current required for the pump.

Actual discharging time = $\frac{\text{battery rating in ampere hour}}{\text{total current required for the pump}}$

Discharge rate of the sprayer: The discharge rate of solar powered sprayer was measured from the volume of liquid discharged from the sprayer nozzle in the specified time. The measuring cylinder was used to collect the discharged liquid from the sprayer nozzle and a digital timer was used for recording the discharge time. The procedure was repeated three times and the mean discharge rate in litre per minute was calculated using the following equation (3) (kepner and EL Barger 2018)

$$DR = \frac{v}{t} \quad ....(3)$$

Where, DR = discharge rate (L min^{-1}), v = volume of liquid collected in cylinder (L) and t = time (min)

Application rate: The spray application rate depends on discharge rate and effective field capacity. The following equation (4) (Kepner and Barger 2018) was used to calculate the application rate for both single nozzle and double nozzle.

$$AR = \frac{Q}{EFC} \quad \text{………..…(4)}$$

Where, AR = application rate (L ha^{-1}), Q = discharge rate over nozzle (L min^{-1}) and EFC = effective field capacity (ha min^{-1}).

Efficiency of the pump: Efficiency of the pump was measured for both single nozzle discharge and double nozzle discharge. The following equation (5) was used to calculate the efficiency of the pump.

$$EP = \frac{\text{Actual discharge}}{\text{Theoretical discharge}} \quad \text{……………(5)}$$

Where, EP = efficiency of the pump (%)

Travelling speed: The speed of the machine was determined by using the following equation (6) (Hunt 2015).

$$S = \frac{d}{t} \quad \text{…………..…(6)}$$

Where, S = travelling speed (ms^{-1}), d = distance traveled (m) and t = time (s)

Theoretical field capacity: The theoretical field capacity is the rate of field coverage that would be obtained if the machine performs its function 100% of the time at the rated forward speed and always covers 100% of its rated width (Kepner and Barger 2018) Therefore,

$$C_{th} = \frac{SW}{c} \quad \text{……………(7)}$$

Where, C_{th} = theoretical field capacity (ha hr^{-1}), S = forward speed (km hr^{-1}), W = rated width (m) and c = constant (10).

Effective field capacity: The effective field capacity is the actual average rate of field coverage by the sprayer and calculated using the following equation (8) ((Hunt 2015).

$$C_{eff} = \frac{A}{T} \quad \text{………..…(8)}$$

Where, C_{eff} = effective field capacity (ha min^{-1}), A = total area covered (ha) and T = total time (min)

Field efficiency: It is the ratio of the effective field capacity to theoretical field capacity. The field efficiency of the sprayer was calculated using the following equation (9) (Kepner and Barger 2018).

$$F_{eff} = \frac{Ceff}{Cth} \times 100 \quad \text{...……..… (9)}$$

Where, F_{eff} = Field efficiency (%), C_{eff} = Effective field capacity (ha hr^{-1}) and C_{th} = Theoretical field capacity (ha hr^{-1}).

Operating cost: The selection of machine for agricultural activities usually depends on least cost operation criteria. The operating cost of solar powered sprayer consists of (a) fixed cost (depreciation and interest on investment) and (b) variable cost (labor and repair and maintenance cost).

Fixed cost: In this study, the straight line method was used to calculate the depreciation using the following equation (10) (Barnerd and Nix 1979)

$$D = \frac{P-S}{L} \quad \ldots\ldots\ldots\ldots(10)$$

Where, D = depreciation cost (Tk yr^{-1}), P = purchase price of the machine or implement (Tk), Salvage value (Tk), and L = life of the machine or implement (yr).

The interest on investment in solar powered sprayer is included in fixed cost estimation. The following equation (11) was used for the calculation of interest on investment.

$$I = \frac{P+S}{2} \times i \quad \ldots\ldots\ldots\ldots (11)$$

Where, i = interest rate (decimal)

Variable cost: The variable cost is one, which changes when the level of output alters and vary in total in proportion to annual use but is approximately constant per ha (Barnerd and Nix 1979). The variable cost of solar powered sprayer depends on labor and repair & maintenance cost for each field operation. The cost of labor and repair & maintenance cost (1% of purchase price) was calculated in Tk hr^{-1}.

Operating cost: All calculated fixed cost and variable cost were converted into Tk ha^{-1} and the summation of fixed and variable cost gave the operating cost of solar powered sprayer in Tk ha^{-1}.

$$TC = FC + VC \quad \ldots\ldots\ldots\ldots\ldots (12)$$

Where, TC = total operating cost (Tk), FC = fixed cost (Tk) and VC = variable cost (Tk)

Capital Recovery Factor (CRF): A capital recovery factor was used to combine the total depreciation and interest changed into a series of equal annual payments at compound interest. These payments plus the interest on the depreciated amount can be used to estimate the capital consumption (CC) of farm equipment as-

$$CC = (P - S)\, CRF + S \times i \quad \ldots\ldots\ldots\ldots\ldots (13)$$

Where, $CRF = i(1+i)^L / (1+i)^L - 1$, and i = interest rate (decimal)

Annual operating cost: The annual operating cost of solar powered sprayer was determined by the summation of fixed and variable cost. The following equation was used to calculate the annual operating cost of solar powered sprayer.

$$AC = FC + (VC \times U) \quad \ldots\ldots\ldots\ldots\ldots (14)$$

Where, AC = Annual cost (Tk), FC = fixed cost (Tk), VC = variable cost (Tk) and U = hours of use

Data analysis: After data collection, data were coded, compiled, tabulated and analyzed by MS Excel (Microsoft Excel, Microsoft, USA) in accordance with the objectives of the study.

RESULTS AND DISCUSSION

Measurement of pressure, flow rate, efficiency and plot performance curve

Where, Pump rated discharge, Q = 3 lit/min

Single nozzle discharge, $Q_1 = 2.5$ lit/min

Double nozzle discharge, $Q_2 = 2.8$ lit/min

Efficiency of the pump, $Ep_1 = \frac{\text{Actual discharge}}{\text{Theoretical discharge}} = \frac{2.5}{3} \times 100 = 83.33\%$

Efficiency of the pump, $Ep_2 = \frac{\text{Actual discharge}}{\text{Theoretical discharge}} = \frac{2.8}{3} \times 100 = 93.33\%$

Table 2. Measurement of pressure and discharge

Trial No.	Nozzle	Pressure(P), bar	Discharge (Q), lit/min
1.		2.097	2.5
2.	1	2.049	2.55
3.		2.073	2.5
1.		1.549	2.8
2.	2	1.612	2.75
3.		1.581	2.7

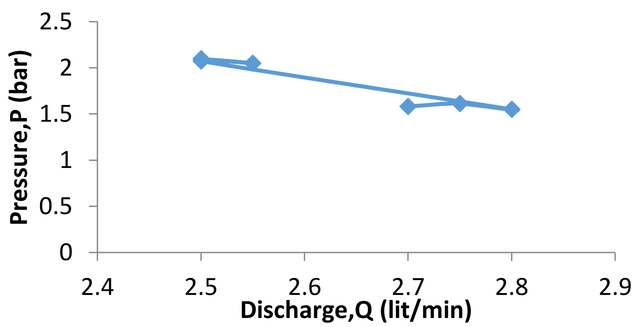

Figure 5. Performance curve

The highest pressure and lowest discharge developed in the pump was 2.097 bar and 2.5 lit/min for single nozzle (Table 2). On the other hand, the lowest pressure and highest discharge developed in the pump were 1.549 bar and 2.8 lit/min for double nozzle (Figure 5).

Measurement of spraying time and pressure of the sprayer

Table 3. Measurement of pressure and time

Sprayer type	Area	Pressure(P), bar	Trial No.	Spraying time	Average time
Solar power	1	4-4.5	1	1 min 20 sec	1 min 20 sec
			2	1 min 14 sec	
			3	1 min 26 sec	
Manual	1	1.5-2	1	2 min 17 sec	2 min 19 sec
			2	2 min 25 sec	
			3	2 min 15 sec	

The solar operated sprayer works on 4- 4.5 bar and coverage the spraying 1 decimal area, the average time 1 min 20 second required. On the other hand, the hand operated sprayer works on 1.5- 2 bar and coverage the spraying 1 decimal area, the average time 2 min 19 second required (Table 3). Here the proposed sprayer almost 58% time saving to hand operated sprayer.

Fabrication cost of the machine: The total fabrication cost of the sprayer was Tk 6230 (Table 4). It is inexpensive as compared to other machines that are available in the market. The fuel cost is zero due to operation by solar power (Table 5). Also one person, even a woman can operate this machine efficiently and smoothly.

Table 4. Fabrication cost of solar powered sprayer

Items	Cost (Tk)
Design of frame	1650
Coloring of frame	150
DC motor with pump	470
Hose pipe (10 feet)	80
Connector	100
Solar panel	700
Controller	220
DC Battery	850
Weir	60
Pressure gauge	250
Spray gun	140
Trolley wheel	160
Storage tank	180
Screw	50
Water level indicator	870
Others	300
Total cost (Tk)	6,230

Table 5. Technical performance of the solar powered sprayer

Particulars	Observations
Theoretical field capacity (ha hr^{-1})	0.08
Theoretical field capacity (ha day^{-1})	0.64
Effective field capacity (ha hr^{-1})	0.065
Effective field capacity (ha day^{-1})	0.52
Field efficiency (%)	81.2

Operating cost of the machine: The fixed cost and variable cost of a solar powered sprayer was 28 Tk ha^{-1} and 773 Tk ha^{-1}. The operating cost of solar powered sprayer was 802 Tk ha^{-1} which was lower than the manual operation (Table 6). The capital recovery factor, capital consumption and annual cost of the solar operated sprayer were 0.26, Tk 1520 and Tk 41665, respectively.

Table 6. Operating cost of solar powered sprayer

Item	Amount
Fixed cost	
Depreciation (Tk yr^{-1})	1122
Interest on investment (Tk yr^{-1})	343
Total fixed cost	
Tk yr^{-1}	1465
Tk hr^{-1}	1.83
Tk ha^{-1}	28
Variable cost	
Labor (Tk hr^{-1})	50
Repair and maintenance(Tk hr^{-1})	0.25
Total variable cost	
Tk ha^{-1}	773
Tk hr^{-1}	50.25
Operating cost	
Tk hr^{-1}	52.08
Tk ha^{-1}	802
Capital Recovery Factor	0.26
Capital consumption (Tk)	1520
Annual cost(Tk yr^{-1})	41665

CONCLUSION

The battery actual discharging time is 4.1 hour and discharging time is 3.28 hour, when we did not use 20% of the rated current (Charvani *et al.* 2017). Then, we evaluated the performance of battery is 80% when weather is not good. Pump efficiency almost 83.33% found for single nozzle and 93.33% for double nozzle and the sprayer is 58% time saving than manual sprayer. The operating cost of the machine was 802 Tk ha^{-1}. Also found capital recovery factor, capital consumption and annual cost of the solar operated sprayer were 0.26, Tk 1520 and Tk 41665, respectively. Besides these, it requires less effort and less maintenance cost than conventional sprayer.

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