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Design, Modeling and Fabrication of a Portable Solar Powered Suction Pump for Use in Industries and Autoclinics

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ABSTRACT

Solar powered systems have been built for various applications ranging from public lighting to water supply units but robust efforts have not been made in the development of pumping systems that can effectively replace the manually operated pumps used in field applications. Designing a machine that can pump the fluid without the need of so much energy on the part of the operator as well as boycott the use of direct electricity will hence be a reasonable contribution to field of maintenance and other relevant fields where such pumps will be required. The methodology adopted for this study involves detailed system design and analysis of a prototype of the pump system for actual implementation. In respect to the energy source, a Solar Photovoltaic system has been developed which is backed up by a battery bank such that the system can function effectively even when disconnected from the PV array. A 65 W PV panel was used alongside a 36 Ah battery bank. The system is designed to be a 12 V DC Charging system and 220-230V AC supply system. A 500 W DC to AC power inverter was used to achieve the transition for implementation. A review of pump technologies and alternative energy applications (Solar Photovoltaic energy technologies) in the study location was undertaken. Finally, the characteristics relationship between the flow rate and the head of the solar powered pump was determined and represented on a graph. It was observed from the graph that the rate of change of the flow rate is inversely proportional to the increasing head. And the highest flow rate is obtained when the head is 0.25m with a corresponding flow rate of 0.040 m^3/s and highest efficiency of 91.153%. The outcome of this study will find useful applications as well as give reasonable contribution to the field of maintenance, and other relevant fields where such pumps will be required such as vegetable and palm oil production companies.

Keywords : Portable Solar, Solar Photovoltaic system, Spark-ignition, Deep Cycle, Li-ion battery

I. INTRODUCTION

(Mario, 2001). This project models a portable solar powered suction pump. Pumps are devices that transfer fluids (liquid or gas) from one point to another through some mechanical means. Pumps generally have being in use for centuries in different fields of application and most especially in the engineering field (Vijaypratap, 2017). The project intends to bridge the gap between a manually operated rotary pump and an extremely sophisticated liquid transfer pumps.

Transfer of liquids can be very difficult, time consuming and frustrating especially in the automotive Maintenance field where liquids – oil and coolant – are needed to be transferred from their containers into different parts of the machines for proper lubrication. Fluids used, many a time, are needed to be contained such that there will be no spillage, hence, the need for a safe transfer of such fluids through a closed cross section. Pumps operate by some mechanism (typically reciprocating or rotary), and consume energy to perform mechanical work by moving the fluid. Pumps operate via many energy sources, including manual operation, electricity, engines, or wind power, come in many sizes, from microscopic for use in medical applications to large industrial pumps (Woodford and Chris, 2008).

When it comes to field applications where electricity may not be available or the use of electrically powered pumps may be hazardous because of sparks, making electricity powered pumps less efficient. However, in the use of hand operated pumps so much energy is required to be imputed on the part of the operator. Designing a machine that can pump the fluid without the need of so much energy on the part of the operator as well as boycott the use of direct electricity will hence be a reasonable contribution to field of maintenance and other relevant fields where such pumps will be required.

II. METHODS AND MATERIAL

The solar powered oil pump which is intended to drive and transfer fluids from one point say from a container into other points where it is needed is made up of the following parts to complete the full assembly :

A rotary vane pump which consists of: pump housing, rotor, vanes, springs and also a solar panel, a motor unit, a switch for the control and pipes to be used for suction and discharge of the liquid.

The solar charging unit consists mainly the solar array panel grid, the charge controller, and electrical panels.

2.1 Rotary Vane Pump

The type of pump used is the rotary vane pump. This is due to the reason that it is the cheapest type of pump available. The schematic of the rotary vane pump has been provided in Fig. 1.

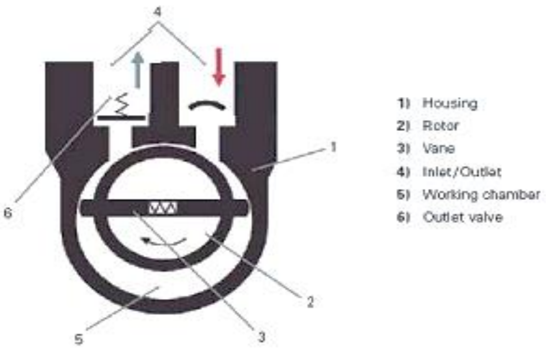

Figure 1. The schematic of a typical rotary vane pump

2.2 The Charging Unit

The charging unit consists of a unit where the pump can be charged. This will give room for the mobility of the pump especially in field applications. This unit consists of the panel array, the mounting pole(s), the connecting cables and the charging controller. Electricity from solar photovoltaic panels is direct current (dc). It does not change voltage or polarity.

2.3 The Charge Controller

Without a charge controller the panels can force too much electricity into the battery and overcharge it. When a battery is overcharged, it loses water rapidly, gets hot and may be damaged. Figure 2 shows the real-life view of the charge controller. Figure 3 illustrates how charge controller links up with the solar panels.

Figure 2. The charge controller

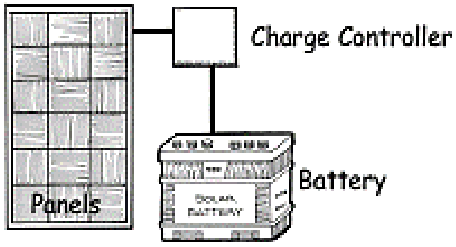

Figure 3. The charge controller as connected to the battery and panel

2.4 The Battery

The battery stores electricity produced by a solar panel for later use. It is an important part of solar PV systems that supply electricity at night or other times when the solar panel is not producing power. The battery is one of the most expensive parts of a PV system. It also has the shortest life and is easily damaged by poor maintenance or incorrect use. The type of battery most often used in a PV system is called a lead-acid battery. Other types includes: Spark-ignition, Deep Cycle, Li-ion battery among others. The battery used here is a 12V battery which is a single unit battery (can also be connected in series or parallel) in order to get the required amperage to power the system.

Figure 4. The 36Ah battery employed in the system *(This is a spark-ignition battery)*

2.5 The Inverter

The pump to be driven is an AC powered pump, hence the need to convert the direct current obtained from the solar panels to alternating current for pump use.

Figure 5. The 500W inverter and its connecting probes

2.6 Solar Panels

The amount of power to be developed in the system was determined with the calculations as provided in latter sections. The sizing of the suitable solar panels was also carried out.

2.7 Basic Calculations carried out to Determine Component Specifications

Below is an overview of the ratings and specifications of the components to be implemented in the design:

Motor type: Brushless AC Motor
Voltage: 12V
Torque: This lies within the range 0.5Nm – 1.5 Nm
Continuous current (A): This lies within the range 2.1A-8.7A
Voltage: 220-230V
Continuous current (A): 0.22A
Power: 30 W.

However, at the initial pick up of the pump, it will use three times the indicated value which for this pump is 90 W (i.e. 30 x 3). In order to give space for an upgrade as well as safety margin; 150 W value of power is considered.

The flow rate: Q is approximately 1 L/cycle or 0.001 m^3/cycle

Q=1 liter/cycle
= 0.001m^3/cycle

Estimated number of turns per minute for the manually operated pump is given as:

N = 40 rpm

Hence the flow rate can be obtained as:

Q = 0.001m³/cycle x 40 rpm

= 0.04 m³/min

= $\frac{0.04}{60}$ m³/s

Q = 6.667×10^{-4} m³/s

Hence, the flow rate obtained by the manual pump is approximately equal to 6.667 x 10-4 m³/s

Power required to drive the pump is given by the equation:

$$P = \rho gHQ \qquad (1)$$

where,

P is the input power required to drive the pump (W)
ρ is the density of the fluid to be pumped (kg/m³)
H is the height / head of the fluid to be pumped (m)
g is the acceleration due to gravity (m/s²)
Q is the volume flow rate of the fluid involved (m³/s)
The density is assumed to be that of a highly dense fluid of about 1500 kg/m³ density.
The height is assumed not to be more than 2 m based on the intended areas of application.
The acceleration due to gravity is a standard value which is equal to 9.81 m/s²
Hence, the power, P can be estimated from equation (1) as:

P = 1500 x 9.81 x 2 x 6.667×10^{-4}
P = 19.62 watts

Hence, the power expended in driving the pump manually is about 20 watt power.

For the solar-powered system:

The desired speed is 5 times the speed of the manually operated pump. This implies that for a minute, the desired number of turns will be 40 turns x 5. And that gives 200 turns for a single minute. This is done in order to specify the speed of the motor required to power the pump. The speed of the motor is then 200 rpm.

Maintaining all other parameters as stated above, the required flow rate then becomes :

Q = 0.001 x 200 = 0.2

= $\frac{0.2}{60}$

Q = 0.00333 L/cycle or m³/cycle

Hence, the power, P can be estimated as:

P = 1500 x 9.81 x 2 x 0.00333
P = 98.1 watt

Taking note of the efficiency: For the efficiency of 70 percent: (0.7)

Hence, the power becomes:

P = $\frac{P}{0.7}$

= $\frac{98.1}{0.7}$ = 140.142 W

From the pump motor specifications, the power required is 30 W, which is the lower band of the power required by the motor. (P = 150 W)
Maximum current (A) I_{max} = 0.25 A
Voltage 'V' = 220-230V

Thus, for two (2) hours, Energy required to power the motor is given by:

P = 150W

$$E = P \times t \qquad (2)$$

where,

E is energy required to power the motor
P is power required by the motor
T is time required for system to be in operation

E = 150 x 2

E = 300 Wh

Hence, the energy required to run the motor for 2 hours is 300 Wh.

To further determine the battery capacity, the battery capacity is measured in Ampere Hours (Ah),

Energy from battery = Battery voltage x Battery capacity
(3)

Hence, the Battery capacity = $\frac{\text{Energy required from battery}}{\text{Battery voltage}}$
(4)

$$= \frac{300\text{Wh}}{12\text{ V}}$$

Recall, P = IV (5)

W = A x V (6)

E = P x t = A x V x h (7)

$$\frac{\text{Energy}}{\text{Volt}} = \frac{\text{P x t}}{V} = \frac{\text{A x V x h}}{V}$$

= Ah

Hence, Battery capacity is 25 Ah

Battery specification: 25Ah / 12V battery

However, for safety reasons, considering a level of tolerance and market availability of the battery a battery capacity of 36 Ah capacity will be used. The battery specification to be used is 36 Ah / 12 V.

To determine the size or capacity of the charge controller, the equation 8 is suggested by:

Charge controller = 1.3 x I_{sc} (8)

where, 1.3 is a constant value determined by a control factor

I_{sc} is the short circuit current

The Pulse with modulation was then obtained as follows:

Charge controller = 1.3 x I_{sc}

where, I_{sc} = 7.7 A

= 10A / 12V

Hence, the capacity of the charge controller needed to control the charges that get in and out of the battery is about 10A/12V controller.

III. RESULTS AND DISCUSSION

The specification of the electromechanical pump is shown in Table 1:

TABLE 1

Desired flow rate (Q)	0.00333m³/s
Rated voltage (V)	220 – 230 volts (AC)
Maximum Short circuit current (I_{sc})	7.7 A
Speed of rotation (N)	200 rpm
Frequency	50 Hz
Maximum power output	150 W
Maximum head (H)	2 m
Maximum fluid density (p_{max})	1500Kg/m³
Acceleration due to gravity (g)	9.81m/s²
Designed efficiency	70%

SPECIFICATIONS OF ELECTROMECHANICAL PUMP

The pump specifications as obtained via calculations have been provided in Table 2.

TABLE 2

CALCULATED PUMP SPECIFICATIONS

Motor type	Brushless AC motor
Rated voltage	220 – 230 volts (AC)
Continuous current	0.22 A
Rated power	30 W
Frequency	50 Hz
Startup power	100 W

The equation that relates the power to other parameters of the pump is given as:

$$P = pgHQ \quad (9)$$

We have the head coefficient as well as the flow coefficient of the pump. The head (H) of the pump related with the flow rate of the pump as shown in the relation:

$$Q = k/H \quad (10)$$

The flow rate is inversely proportional to the head such that the higher the head, the lesser the flow rate of the pump.

The maximum theoretical head has been designed to be 2 m based on the desired area of application.

However, by varying the head at an interval of 0.25 steps, we can obtain the flow rate as tabulated in the table below taking other parameters of the relation as a constant. The obtained data has been provided in Table 3, and Fig. 6 shows the result of the plotted graph.

TABLE 3

VARIATION OF THE HEAD COEFFICIENT AND THE FLOW COEFFICIENT OF THE PUMP

Head (H)	Flow rate (Q)
0.25	0.03956
0.50	0.01978
0.75	0.01318
1.00	0.00989
1.25	0.00791
1.50	0.00659
1.75	0.00565
2.00	0.00494

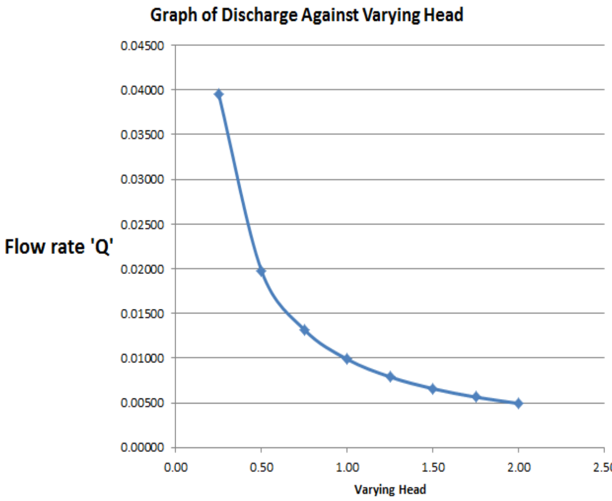

Figure 6. Graph of discharge against varying head

The relation used to obtain the values of the flow rate is given by:

$$Q = P/pgH \quad (11)$$

P = 97.1 W

P_{max} = 1500Kg/m^3

Considering different types of fluids having different density and viscosity, we can obtain the relationship between the flow rate of the fluid and the density and viscosity of the different types of fluids. The flow rate is inversely proportional to the density as well as the viscosity of the fluids that is being considered. The fluids considered, their density and viscosity are shown in Table 4.

TABLE 4

A TABLE SHOWING THE POSSIBLE FLUIDS THAT COULD BE TRANSFERRED

Fluid type	**Density (kg/m^3)**	**Viscosity (mPa.s)**

Water (fresh)	1000	0.89
Water (salt)	1030	0.91
Liquid oxygen(at about -219⁰c)	1141	0.59
Sodium	970	0.72
Glycerol	1216	1.41
Diesel	900	0.55
Petrol	719.7	0.60
Engine oil (at 20⁰c)	888.1	0.51
Hydraulic oil (at 15.6⁰c)	880	0.50
Transmission oil (at 70⁰c)	833.3	1.22
coolant	1113.2	1.30
Cooking oil	920	0.45

The obtained data while considering different fluids and discharge per time has been provided in Table 5, and Fig. 7 shows the corresponding result of the plotted graph.

TABLE 5

VARYING DISCHARGE CONSIDERING DIFFERENT FLUID TYPES

Fluid type	**Density (kg/m^3)**	**Flow rate (m^3)**
Water (fresh)	1000	0.004595
Water (salt)	1030	0.00480
Liquid oxygen(at about -219⁰c)	1141	0.00434
Sodium	970	0.00510
Glycerol	1216	0.00407
Diesel	900	0.00550
Petrol	719.7	0.00688
Engine oil (at 20⁰c)	888.1	0.00557
Hydraulic oil (at 15.6⁰c)	880	0.00562
Transmission oil (at 70⁰c)	833.3	0.00594
coolant	1113.2	0.00445
Cooking oil	920	0.00538

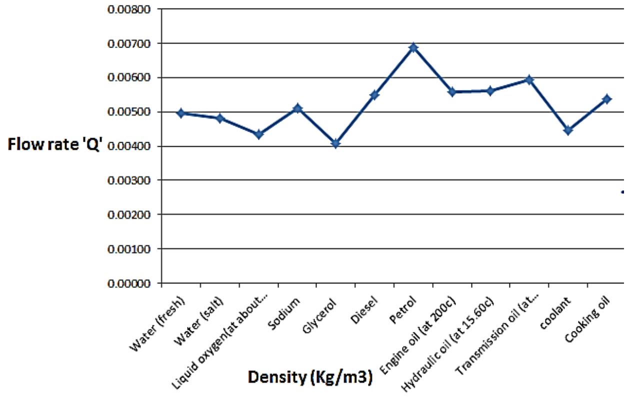

Figure 7. Graph of discharge against varying density (Different fluid types)

Characteristics table for the pump can be obtained has been provided in Table 6. The corresponding graphical representation has also been provided in Fig. 8.

TABLE 6

CHARACTERISTICS TABLE FOR THE PUMP

Head (H)	**Flow rate (Q)**	**Efficiency (%)**
2.00	0.03956	91.153
2.00	0.01978	82.305
2.00	0.01318	73.445
2.00	0.00989	64.611
2.00	0.00791	55.752
2.00	0.00659	46.889
2.00	0.00565	38.053
2.00	0.00494	29.150

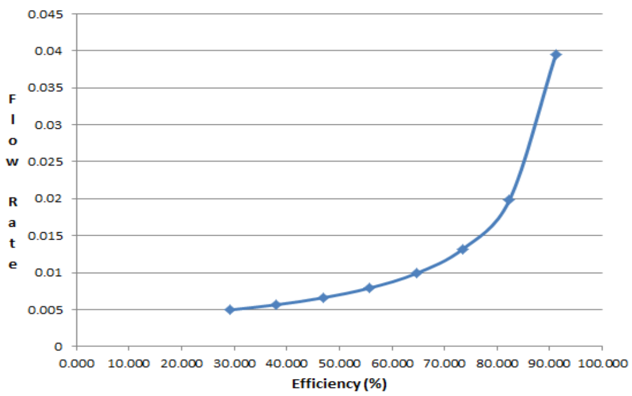

Figure 8. Graph of discharge against efficiency at a constant head

IV. CONCLUSION

The fabricated system is of great aesthetical value, cost-effective and troubleshooting compliant. The designed system has also been able to meet up with the objectives earlier stated in the introduction, the Chapter One of this write up. The fabricated system has been able to bridge the gap between hand operated pumps and electric power based pumps, by combining the characteristics of easy fluid transference with a discharge of up to 21 l/min and a solar energy source.

Manually operated rotary vane oil pumps are less efficient and require the use of much man power to drive them, while sophisticated electricity powered at the other end are expensive and may not be feasible for use especially while maintaining equipment in the field. The need for the provision of a faster and more efficient means of fluid transfer from one point to another without the need for manual operation or grid electricity inspired the work of this project. This has been achieved by combining the effectiveness of a locally sourced pump and Solar Technology to design and fabricate a product that performs the desired function.

The importance of making shift in the source of energy to power most of the mechanical systems that are being used which is made cost effective has been put forth and utilization of solar power in providing the energy source in place of the conventional electricity is implemented. In respect to the energy source, a Solar Photovoltaic system has been developed which is backed up by a battery bank such that the system can function effectively even when disconnected from the PV array. A 65 W PV panel was used alongside a 36 Ah battery bank. The system is designed to be a 12 V DC Charging system and 220 -230V AC supply system. A 500 W DC to AC power inverter was used to achieve the transition for implementation. On the other hand, a portable 30 W, 0.22 A fluid transfer drain pump was used; the detailed design calculations of the solar system requirements and the required power of the pump was done in the write up; a model was designed and a prototype was fabricated. Performance evaluation was carried out and the obtained results are accurately determined and shown in the report. Water was used as the sample fluid for the analysis and performance evaluation carried out on the fabricated pump. Also the discharge and charging rates of the battery was evaluated. The evaluation shows the different rates of flow (discharge) at different heads of which it was deduced that the rate of flow is inversely proportional to the head of the pump. The efficiency of the pump increases as the flow rate increases and was maximum at a head of 0.25 m with the efficiency of 91.153%.

The result at the end of the project is a pump that can be operated at the most convenience of the operator which will not need the use of electricity as well as eliminate the use of manpower as a drive. This gives a remarkable contribution to the relevant industries, field work and several small scale bases where it can be adapted for use.

Nomenclatures

A	Amperes
E	Energy (Wh)
g	acceleration due to gravity (m/s^2)
H	height (m)
L	Length (m)
P	Power
Q	Flow Rate (m^3/s)
t	time (secs)
V	Voltage
W	Watt
Wh	Watt Hour

Greek Symbols

ρ	Density (Kg/m^3)

Abbreviations

AC	Alternating current
DC	Direct Current
I_{max}	Maximum Current
I_{sc}	Short Circuit current

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