Comparison of Solar Powered Water Pumping Systems which use Diaphragm Pumps

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ABSTRACT

Four solar PV powered diaphragm pumps were tested at different simulated pumping depths at the USDA-ARS research laboratory near Bushland, TX. Two of the pumps were designed for intermediate pumping depths (30 to 70 meters), and the other two pumps were designed for moderate flow rates (9 to 15 liters/min). Using the solar resource of Bushland, TX and the ARS Laboratory PV panel angle procedure, the estimated average daily water volume of the diaphragm pump systems tested varied from 1300 to 3650 liters/day at a 30 meter pumping depth and 750 to 1650 liters/day at a 70 meter pumping depth. The maximum pump efficiencies of the diaphragm pumps tested varied from 25 to 48%. The graphs depicted in this paper should help a PV pump installer determine which diaphragm pump should be selected or whether another type pump is needed.

1. INTRODUCTION

1.1 Background

At the USDA-ARS Conservation and Production Research Laboratory (CPRL) near Bushland, TX, in the Texas Panhandle, research has been conducted on wind powered watering pumping systems since 1978 and solar powered water pumping systems since 1992. Since our facility is in a semi-arid climate with a declining underground aquifer, our main focus is in determining the most efficient way of pumping underground water for livestock, domestic use, and irrigation through use of wind energy, solar energy, or a combination of both. The Bushland ARS facility has a good solar resource but not as good as far West Texas (Fig 1). Several papers have been written on the performance of PV water pumping systems at CPRL including the following:

1. Performance of PV powered diaphragm pump (1).
2. Comparison of wind to solar powered water pumping systems (2).
3. Fixed versus passive tracking PV panels (3, 5).
4. Performance of PV powered centrifugal pump (4).
5. Comparison of a-Si to CdTe PV modules (6).
6. Affect of Panel Temperature on PV pumping systems(7).
7. Performance of a PV powered helical pump (8).

There are four types of pumps which have been used with solar PV water pumping systems – piston, diaphragm, helical, and centrifugal. This paper is on the performance of four different solar powered diaphragm pumps. Two of the diaphragm pumps were designed for pumping at low flow rates (2 to 8 lpm) and for low to moderate pumping depths (30 to 70 meters), and the other two diaphragm pumps were designed for moderate flow (9 to 15 lpm) and shallow

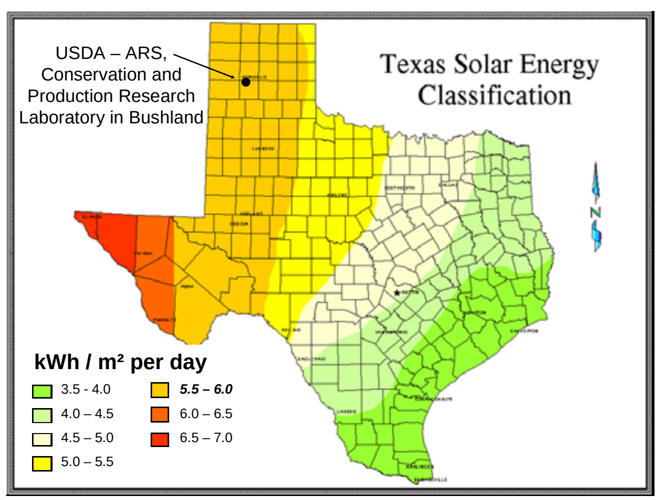

Fig. 1. Solar Resource in the State of Texas (Fixed PV Panels at angle = latitude).

pumping depths (10 to 30 meters). The pumps designed for moderate pumping depths were tested at moderate pumping depths of 20, 30, 50, and 70 meters at 100 Watts of PV, and also at 50 and 70 meter pumping depths at 160 Watts of PV. The higher flow (Quad) pumps have so far been tested at 20 and 30 meter pumping depths with 160 Watts of PV.

1.2 Test Setup, Instrumentation, and Data Acquisition

Of the four diaphragm pumps tested, the two moderate head diaphragm pumps were tested side by side and after this testing was finished the moderate flow/Quad diaphragm pumps were tested simultaneously. The diaphragm pumps were installed in underground water sumps inside a building and the pumping depth was varied with a pressure regulating valve. Two of the pumps (a moderate head pump and a Quad pump made by the same manufacturer) were wired to an above ground controller which had a built-in switch, so power from the PV modules could be disconnected. Another diaphragm pump was connected to its above ground controller, but it didn't have an on/off switch, so it was also connected to a disconnect switch. The fourth diaphragm pump was tested without an above ground controller (at the manufacturer's request), so it was connected directly to a shutoff switch. From the controller or shutoff switch, the moderate head diaphragm pumps were connected to two 12-Volt 50-Watt multi-crystalline modules (connected in series) for first part of the testing and for the rest of the test the pumps were connected to a single 24-Volt 160-Watt multi-crystalline module. The moderate flow/Quad diaphragm pumps were connected only to the 24-Volt 160-Watt PV module. Additional information on the diaphragm pumps used and the instrumentation discussed below can be found in the Appendix.

Some low water flow rate transducers were used in this testing, so we could obtain an accuracy of +/- 0.15 lpm. These flow meters required 100 micron filters to keep the paddles from being damaged by particles in the water, and after a couple of different 5-10 micron filters were tried (not successful since they both clogged within a few days), we purchased a couple of 75 micron drip irrigation filters which only needed to be cleaned every 1 to 2 months. The water pressure transducers used (these were needed to measure the simulated water pumping depth) were accurate within +/- 1.0 psig (0.7 meters). The DC voltage and current between the PV modules and the above ground controller or disconnect switch were measured with an accuracy of +/-0.5 Volts and +/-0.1 Amps, respectively. The pyranometers for measuring solar irradiance were mounted flush with the solar modules, so they recorded the solar radiation incident on the PV panels. The typical accuracy of these pyranometers is +/- 3%, but we calibrated these pyranometers with a pyranometer with +/- 1% accuracy.

All the parameters were measured each second and the average values were recorded every minute on a storage module of a data logger. The stored data were downloaded every week to a PC and then the data were processed (binned in 100 W irradiance bins) with a computer program written by the authors. A log book was also kept which contained daily performance of the systems (daily water volume, flow rate at irradiance of 1000 W/m^2, etc), and any observations or problems that occurred during the testing.

2. RESULTS

2.1 Diaphragm Pump Performance at 30m Head

Fig 2 shows the flow rate versus irradiance of four diaphragm pumps tested at a 30 meter head. The moderate head pumps (MHP1 and MHP2) were powered by 100 Watts of PV and obviously MHP1 pumped significantly more water than MHP2 at this pumping depth (maximum flow rate of MHP1 was approximately double that of MHP2). The Quad (moderately high flow) pumps were powered by 160 Watts of PV and Quad 2 (same pump manufacturer as MHP2) had a significantly higher flow rate than Quad 1 for irradiance levels less than 700 W/m^2, but had a lower flow rate at irradiance levels above 800 W/m^2. The lower flow rate of Quad 1 at the lower irradiance level is due likely to not being connected to an above ground controller which modifies voltage and current to allow the motor to run more efficiently. All four flow rate curves flatten out at a certain irradiance level, and Fig 3 will discuss why.

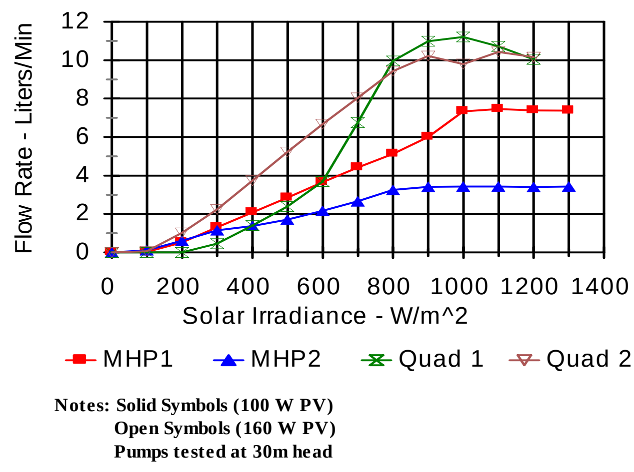

Fig. 2. Measured flow rates at 30 meter head.

Fig 3 shows the DC power pulled from the PV modules by the diaphragm pumps. The power pulled by the MHP1 and MHP2 pumps is almost identical below an irradiance level of 900 W/m^2. However, above this irradiance the MHP2 controller restricts the power to the pump to 65 Watts. For the MHP1 pump, the power to the pump is restricted by the controller to 85 Watts at an irradiance above 1000 W/m^2. For a 30 meter head, increasing the amount of input PV power will increase the amount of water pumped at lower irradiance levels, but the maximum flow rate will always be restricted to 7.5 and 3.2 lpm for the MHP1 pump and the MHP2 pump, respectively. The power curves for the Quad pumps look similar to the flow rate curves which implies they would perform similarly if the Quad 1 had an above ground controller like the Quad 2. The restriction in power for both of the Quad Pumps is in the 130 to 140 Watt range.

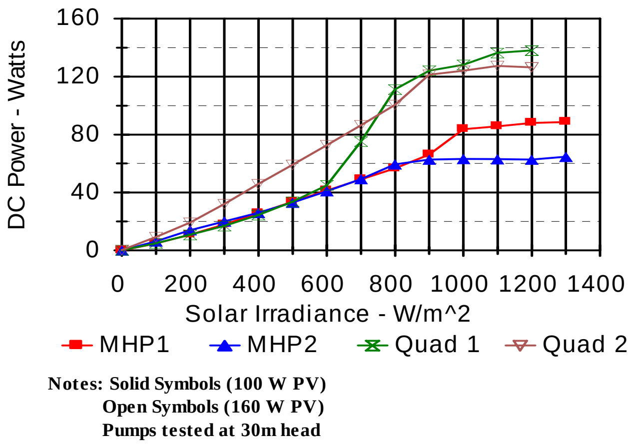

Fig. 3. Measured DC Power (between PV array and Controller/Switch) at 30 meter head.

The pump efficiency for all four diaphragm pumps at a 30 meter pumping depth is shown in Fig 4. The pump efficiency of MHP1 and Quad 2 are very similar with maximum pump efficiency around 42%. Quad 1 also reaches a maximum pump efficiency of 42%, but it has a significantly lower efficiency at lower irradiance. MHP2 has the lowest pump efficiency of all the pumps above an irradiance of 400 W/m^2 – a caveat is that it has the best efficiency at a solar irradiance of 100 W/m^2.

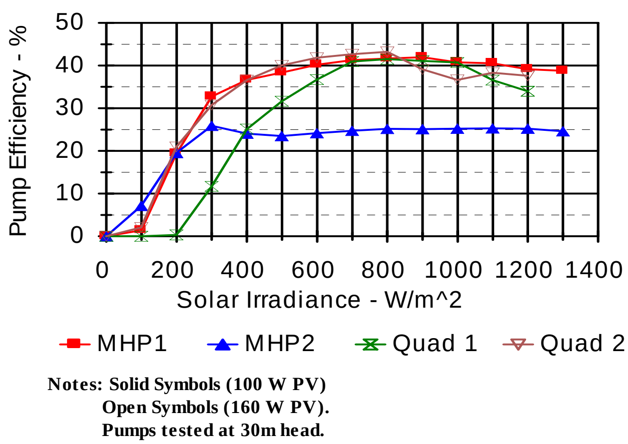

Fig. 4. Calculated Pump Efficiency at 30 meter head.

Fig 5 shows the monthly daily water volume predicted by months for all four diaphragm pumps at a 30 meter pumping depth (used solar resource at Bushland, TX). We should mention how we set the PV panel incidence angle at Bushland every year. Our latitude at Bushland is 35.2^o N. During the spring and summer we set the panel angle to 25^o and during the fall and winter we set the panel angle incidence to 45^o. At noontime we should only be at most 3% low from optimum performance (optimum PV panel angle allows solar radiation to strike the panel exactly perpendicularly – in our case optimum panel angle varies from 11.75^o at summer solstice to 58.65^o at winter solstice) when we change the solar panel incidence angle at the spring and autumnal equinoxes. The irradiance data collected between 1995 and 1999 at Bushland, which was used in the daily water volume calculation, used the procedure described above for amount of time at each irradiance level. No form of PV panel tracking (passive or motorized) was used in this testing. The annual average daily water volume at a 30 meter head for Bushland for each diaphragm pump in ascending order is as follows: MHP2 is 1300 liters/day, MHP1 is 2300 liters/day, Quad 1 is 3300 liters/day, and Quad 2 is 3650 liters/day.

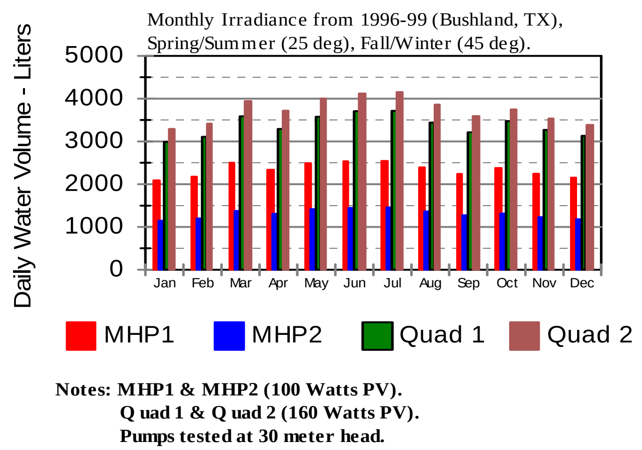

Fig. 5. Calculated Daily Water Volume at 30 meter head.

2.2 Diaphragm Pump Performance at 70m Head

Fig 6 shows the flow rate of MHP1 and MHP2 at a 70 meter pumping depth with 100 and 160 Watts of PV. At this pumping depth and 100 Watt PV input, both these diaphragm pumps had approximately the same flow rate – much different than the result for a 30 meter pumping depth (see Fig 2). However, when the input PV power is increased to 160 Watts, then the flow rate of MHP1 is significantly better than MHP2. The maximum flow rate of MHP2 at a 70 meter head (2.8 lpm) is about 10% less than the maximum flow rate at a 30 meter head (3.2 lpm). However, the maximum flow rate of MHP1 at a 70 meter head (3.2 lpm @ 1100 W/m^2) is less than half that measured at the 30 meter head (7.5 lpm) for the 100 Watt PV input. The maximum flow rate improves significantly (5.4 lpm) when the PV rated power is increased from 100 to 160 Watts PV.

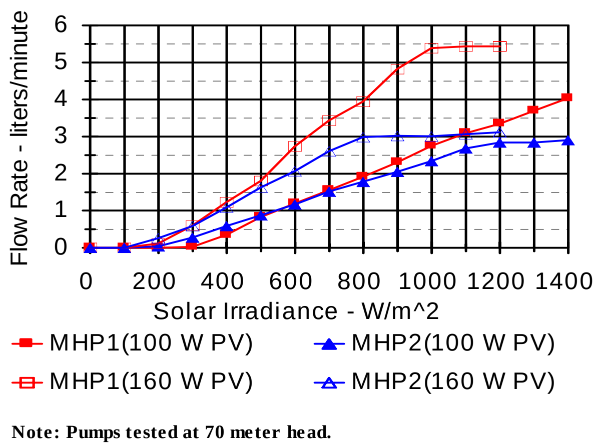

Fig. 6. Measured Flow Rate at 70 meter head.

The power drawn by the MHP1 and MHP2 diaphragm pumps with 100 Watts of PV input is nearly identical (Fig 7). The power drawn by MHP1 and MHP2 diaphragm pumps with 160 Watts of PV is very close to identical until an irradiance of 800 W/m^2 is reached. At 800 W/m^2 the power to MHP2 is restricted to 97 Watts while power to MHP1 is not restricted until an irradiance of 1000 W/m^2 is reached – power restricted to 130 Watts.

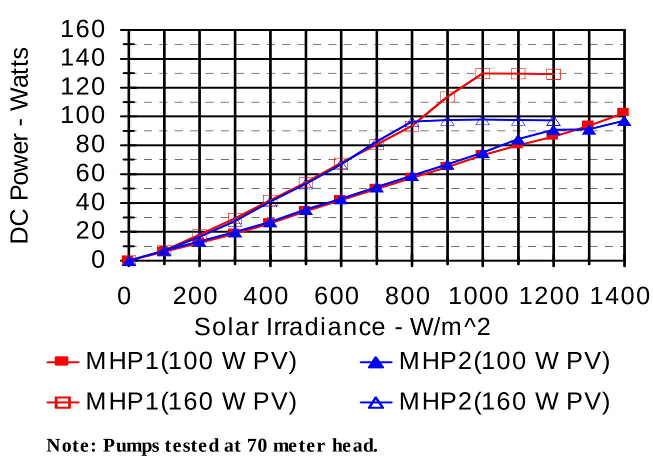

Fig. 7. Measured DC Power (between PV modules and Controller/Switch) at a 70 meter head.

Fig 8 shows the pump efficiency measured for all the diaphragm pump systems tested at a 70 meter pumping depth. The MHP1 diaphragm pump system achieves 48% efficiency with 160 Watts of PV input. The MHP1 pump with 100 Watts of PV achieved a maximum efficiency of 44%. The maximum pump efficiency of the MHP2 pump was significantly higher at 70 meters (35%) than at 30 meters (25%) – refer back to Fig 4.

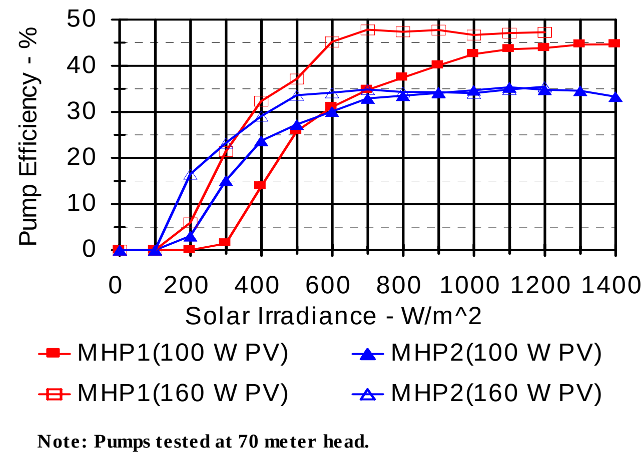

Fig. 8. Calculated Pump Efficiency at 70 meter head.

Fig 9 shows the annual average daily water volume for MHP1 and MHP2 at 100 Watts of PV at Bushland, TX is about the same – 750 to 800 liters/day. However, a significant increase in daily water volume would result for MHP1 and MHP2 if the PV power is increased to 160 Watts – 1650 liters/day and 1100 liters/day, respectively.

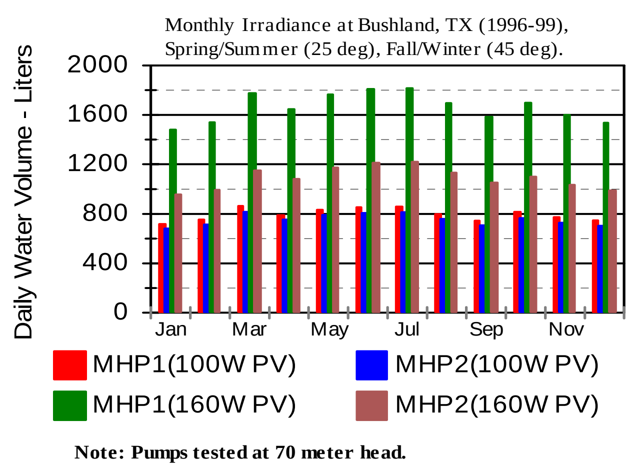

Fig. 9. Calculated Daily Water Volume at 70 meter head.

2.3 Pump Curves of Diaphragm Pumps

Fig 10 shows the predicted annual average daily water volume for all the diaphragm pumps, pumping depths, and PV power inputs tested so far at the ARS lab at Bushland. This graph should help an individual needing a water pumping system to decide which diaphragm pumping system to select or if they need to consider another type pump. The current pumping depth at the USDA-ARS research laboratory near Bushland, TX is 73 meters, so none of the diaphragm pumps tested is rated for Bushland, TX.

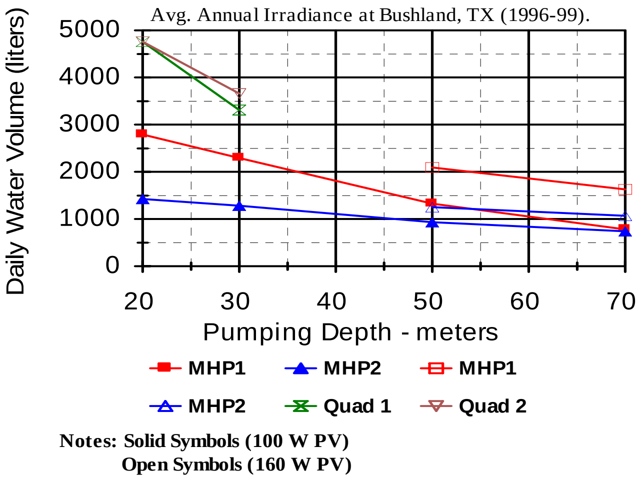

Fig. 10. Pump Curves of Diaphragm Pumps.

3. CONCLUSIONS

Annual daily water volumes of as high as 1650 liters/day and 3650 liters/day were estimated at pumping depths of 70 and 30 meters, respectively for a solar resource similar to that at Bushland, TX. Solar powered diaphragm pumps demonstrated an ability to pump water from a simulated well depth of 70 meters (230 ft) – the previous deepest pumping depth we tested these systems at, and which also demonstrated reliability was 30 meters (98.6 ft). Also, not having an above ground controller on one of the diaphragm pump systems appears to have resulted in a 9% decrease in daily water volume.

The pump curve graph in this paper should help in the selection of the right diaphragm pump for a certain application (daily water volume required & pumping depth). Although the water pumping performance shown in this paper for diaphragm pumps is important, reliability and longevity of the diaphragm pumps are equally important, but were not addressed in this paper. In a previous paper (5) a diaphragm pump tested at a 30 meter pumping depth lasted over six years before failing.

4. ACKNOWLEDGEMENTS

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6. APPENDIX

Below is Table A1 showing information on the instrumentation and diaphragm pumps discussed in this paper. The first column shows the type of instrumentation or the diaphragm pump name used in the paper. The second column is the manufacturer of the instrumentation or the diaphragm pump. The third column is the model name/number of the instrumentation or that of the diaphragm pump.

TABLE A1: Instrumentation and Pump Manufacturers

Type/Name	Manufacturer	Model
Data Logger	Campbell Scientific [a] (CSI)	23x
DC Voltage	CR Magnetics[a]	CR 5310-50
DC Current	CR Magnetics[a]	CR 5210-10
Flow Meter	JLC Int.[a]	824
Pyranometer – 3% accuracy typical	CSI[a]/Li-Cor[a]	LI200X
Pyranometer – 1% accuracy	Eppley[a]	PSP
Pressure	Honeywell[a]	EA 9300101
MHP1	Shurflo[a]	9300
MHP2	Sun Pumps[a]	SDS-D-228
Quad 1	Robison[a]	BL40Q
Quad 2	Sun Pumps[a]	SDS-Q-128

[a] The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA – Agricultural Research Service.

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