To: Professor Hosni
From: Mason Averill
Subject: ME 318 Fluid Mechanics Design Project: Solar Water Pump for Irrigation
Date: 4/12/2020

The purpose of this memo is to communicate the results of the design project for ME 318. The project consisted of designing a solar water pump system for irrigation. The fluid system consisted of a single path pipe with an elevation gain of 109 ft, a total length of 140 ft, multiple fittings, a specified flow rate of 7GPM, a valve, and a pump. The power system consisted of a solar panel(s), which was to be used to power the pump of 55% efficiency. In addition, multiple iterations of the fluid system were to be considered by varying the diameter and material of the pipe. The cost for each iteration, including the associated power system cost, were to be found to select the ideal configuration.

To complete this project, the fluid system was first analyzed for 12 different cases. The cases consisted of 3 different materials of pipe, with 4 different diameters for each material. The power required by the pump was found for each case. The power system considered multiple cases as well, including continuous 24 hours/day flow, 12 hours/day flow, 6 hours/day flow, and 2 hours/day flow. The solar panel requirement for the power system was sized using the result of three different methods, one based on average solar irradiation and the other two based on manufacturer specifications.

The major assumptions made to complete this project included choosing the type of fittings that were to be used, the type of valve that was to be used, the entrance conditions at the pump, and the exit conditions at the storage tank. The pump pickup was assumed to be square-edged, the fittings were all assumed to be 90° and threaded, the valve was assumed to be a ball valve that is wide open during operation, and the exit expansion ratio was assumed to be 0.

The design variables consisted of the pipe material and pipe diameter. The selected materials were cast iron, commercial steel/wrought iron, and galvanized iron. The selected diameters were 0.5”, 1”, 2”, and 3”. The power system was sized for each case.

The 1” diameter pipe was found to be the best choice for each material type, based on the combined cost of the fluid system and power system. All 1” diameter systems required a ½ HP pump and, with continuous flow, 5 LG 370NeON R Solar panels(*Wholesale Solar*). The cheapest overall system consisted of 1” diameter cast iron piping, and with continuous flow, costed $4100.

Though the aforementioned cast iron system was found to be the cheapest, it was not by a significant amount. The system comprised of commercial steel was only ~$300 more than the cast iron system and the system comprised of galvanized iron was only ~$800 more than the cast iron system. Considering the nature of the system, it would be well worth the additional $800 for galvanized iron, as it would considerably extend the lifespan of the system due to the corrosion resistance of galvanized iron.

Objective of Project:

Referring to Figure 1, the objective of this project was to consider multiple materials and diameters of pipe connecting the reservoir to the well. For each configuration, the losses and pump work required were to be found. In addition, the solar power system was to be sized accordingly for each configuration. The total cost was to be found for each configuration, allowing for the selection of the best system.

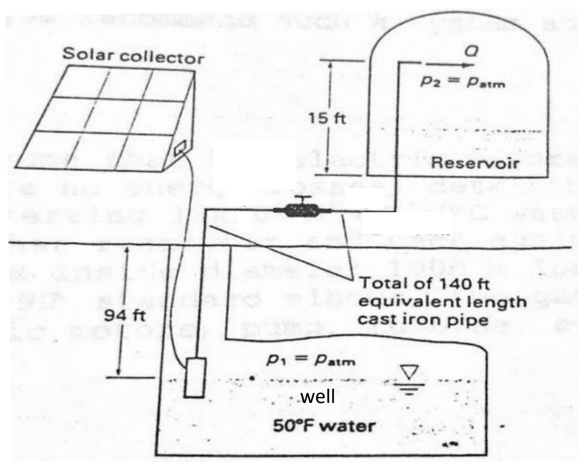

Figure 1-Solar Water Pump System

Design Methodology:

Cast iron, commercial steel/wrought iron, and galvanized iron systems were all considered, with pipe diameters of 0.5", 1", 2", and 3" considered for each material. To determine the pump work required for each configuration, the modified Bernoulli Equation as shown by Equation 1 was utilized.

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 + \frac{\dot{W}}{\dot{m}g} = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_l \qquad \text{Equation 1}$$

With:
$P_1 = P_2 = P_{atm}$=0 [psi Gauge]
$V_1^2 = V_2^2$ (from conservation of mass assuming incompressible fluid)
$z_1 = 0$ (datum)
z_2=139 [ft]
$\dot{W}$=Rate of work by the pump on the fluid [ft-lb/s]
h_l=total head losses [ft]
$\dot{m}$=mass flow rate of the water [lbm/s]
γ=specific weight of water [lbf/ft^3]
g=gravitational constant [ft/s^2]

Applying all known values to Equation 1, and solving explicitly for the rate of work by the pump on the fluid yields Equation 2.

$$\dot{W} = Q\gamma[109 + h_l] \qquad \text{Equation 2}$$

With:
Q=volume flow rate[ft^3/s]

The amount of head loss can be calculated as shown by Equation 3.

$$h_l = h_f + h_m = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g} + \sum K_L \cdot \frac{V^2}{2g} \qquad \text{Equation 3}$$

With:
h_f=head losses due to friction [ft]
h_m=minor head losses due to fittings and valves [ft]
f=friction factor
D=diameter of the pipe [ft]
V=average velocity of the fluid [ft/s]
K_L=head loss due to a fitting or valve

To determine the number of solar panels required based on irradiation, Equation 4 was utilized.

$$P = \eta I A => A = \frac{P}{\eta I} \qquad \text{Equation 4}$$

With:
P=amount of power pump requires=$\frac{\dot{W}}{Pump\ Efficiency}$ [ftlb/s]
η=solar panel efficiency
I=Solar irradiation intensity [ftlb/s/ft^2]
A=area of solar panel required [ft^2]

The number of solar panels required can also be determined by viewing the specifications of a specific solar panel to find its max power output. The issue with this being the value obtained for the max power output of the solar panel is dependent upon many factors, which can vary significantly not only with time of day, but also geographical location.

Major Assumptions:

The major assumptions made to complete this project included choosing the type of fittings that were to be used, the type of valve that was to be used, the entrance conditions at the pump, the exit conditions at the storage tank, the pump efficiency, and the volume flow rate. The pump pickup was assumed to be square-edged (K_L=0.5), all three fittings were assumed to be 90° and threaded (K_L=1.5), the valve was assumed to be a ball valve that is wide open during operation (K_L=0.5), and the exit expansion ratio was assumed to be 0 (K_L=1). Minor losses other than those at the entrance, exit, valve, and elbows were neglected. The flow rate was taken to be 7 GPM and the pump efficiency was taken to be 55%. The solar panel chosen was the LG 370 NeON. It has an area of 18.6 ft^2, a maximum power output of 370W, an efficiency of 21%, and a cost of $495.

Design Variables:

The two different variables considered were pipe material and diameter. By selecting 3 different pipe materials and 4 different diameters, a total of 12 cases were considered. The types of fittings, valves, flow rate, and pump efficiency were taken to be the same for each case.

Results:

Table 1-Fluid System Analysis Results

Fluid System Results				
Case	Pipe Material	Pipe Diameter [in]	Total Head Loss [ft]	Pump HP Required (with inefficiency considered) [HP]
1	CAST IRON	0.5”	355.35	1.49
2	CAST IRON	1”	9.65	0.38
3	CAST IRON	2”	0.31	0.35
4	CAST IRON	3”	0.05	0.35
5	Commercial Steel or Wrought Iron	0.5”	222.54	1.07
6	Commercial Steel or Wrought Iron	1”	7.28	0.37
7	Commercial Steel or Wrought Iron	2”	0.28	0.35
8	Commercial Steel or Wrought Iron	3”	0.04	0.35
9	Galvanized Iron	0.5”	299.11	1.31
10	Galvanized Iron	1”	8.59	0.38
11	Galvanized Iron	2”	0.29	0.35
12	Galvanized Iron	3”	0.04	0.35

As can be seen by reviewing Table 1, there is a significant decrease in both head loss and pump power requirements from the ½” diameter pipe to the 1” diameter pipe for each material type. Increasing the pipe diameter past 1” has relatively negligible effects on the pump power requirements.

Table 2-Power System Analysis Results

Power System Results [Continuous Flow=10080 Gallons/Day]			
Case	Number of Solar Panels Required based on Solar Irradiance	Number of Solar Panels Required based on Manufacturer Specifications and Minimum Duration of Sunlight*	Number of Solar Panels Required based on Manufacturer Specifications and Average Duration of Sunlight*
1	19	20	11
2	5	5	3
3	5	5	3
4	5	5	3
5	14	14	8
6	5	5	3
7	5	5	3
8	5	5	3
9	17	17	10
10	5	5	3
11	5	5	3
12	5	5	3
Power System Results [12Hr/Day Flow=5040 Gallons/Day]			
Case	Number of Solar Panels Required based on Solar Irradiance	Number of Solar Panels Required based on Manufacturer Specifications and Minimum Duration of Sunlight*	Number of Solar Panels Required based on Manufacturer Specifications and Average Duration of Sunlight*
1	10	10	6
2	3	3	2
3	3	3	2
4	3	3	2
5	7	7	4
6	3	3	2
7	3	3	2
8	3	3	2
9	9	9	5
10	3	3	2
11	3	3	2
12	3	3	2

Table 2 cont.

Power System Results [6Hr/Day Flow=2520 Gallons/Day]			
Case	Number of Solar Panels Required based on Solar Irradiance	Number of Solar Panels Required based on Manufacturer Specifications and Minimum Duration of Sunlight*	Number of Solar Panels Required based on Manufacturer Specifications and Average Duration of Sunlight*
1	5	5	3
2	2	2	1
3	2	2	1
4	2	2	1
5	4	4	2
6	2	2	1
7	2	2	1
8	2	2	1
9	5	5	3
10	2	2	1
11	2	2	1
12	2	2	1
Power System Results [2Hr/Day Flow=840 Gallons/Day]			
Case	Number of Solar Panels Required based on Solar Irradiance	Number of Solar Panels Required based on Manufacturer Specifications and Minimum Duration of Sunlight*	Number of Solar Panels Required based on Manufacturer Specifications and Average Duration of Sunlight*
1	2	2	1
2	1	1	1
3	1	1	1
4	1	1	1
5	2	2	1
6	1	1	1
7	1	1	1
8	1	1	1
9	2	2	1
10	1	1	1
11	1	1	1
12	1	1	1

*Number of hours of sunlight based on geographical location of Indianapolis, Indiana. Data from (*Sunshine and Daylight Hours in Indianapolis*)

Table 2 presents the results of many different configurations for the power system. The number of solar panels required is dependent upon, amongst other things, the desired number of gallons/day or total run time of the pump required per day. No specific information is known about the irrigation requirements, so 4 different power system cases were considered for each of the 12 fluid systems. Using Table 2, one can select the appropriate total flow volume per day for their application, as well as the configuration of the fluid system desired, to determine the number of LG 370 NeON solar panels required for their system. Note that in order for the power system to be able to function at any time of day, there must also be a method to store excess energy to be utilized when solar panel output is less than the pump requirement—a battery, or a series of batteries. Determining the number of batteries is beyond the scope of this project and thus it was not considered. To determine the number of solar panels required based on solar irradiance, the intensity of the sunlight had to be found at the geographical location of interest-Indianapolis, Indiana. This value was obtained from *Solar Resource Data, Tools, and Maps*.

By reviewing the data in Table 2, it is clear that the irradiation method and the minimum duration of sunlight using manufacturer specified power output method yield the same result for nearly every case. In addition, both of these calculation techniques consider the worst case power output potential, ensuring that they are very conservative. Due to this, and the similarity in the results between the irradiation method and the minimum duration of sunlight using manufacturer specified power output method, the irradiation results were used to determine the power system cost, shown in Table 3.

Table 3-System Costs

Fluid System Costs				
Case	Pump Cost	Pipe Cost	Fittings and Valves Cost	Total Fluid System Cost
1	1196	514	250	1960
2	751	635	250	1636
3	751	743	250	1744
4	751	1024	250	2025
5	1196	634	250	2080
6	751	968	250	1969
7	751	2063	250	3064
8	751	4230	250	5231
9	1196	953	250	2399
10	751	1508	250	2509
11	751	2685	250	3686
12	751	5355	250	6356
Power System Costs				
Case	Continuous Flow	12 Hr/Day Flow	6 Hr/Day Flow	2Hr/Day Flow
1	9405	4950	2475	990
2	2475	1485	990	495
3	2475	1485	990	495
4	2475	1485	990	495
5	6930	3465	1980	990
6	2475	1485	990	495
7	2475	1485	990	495
8	2475	1485	990	495
9	8415	4455	2475	990
10	2475	1485	990	495
11	2475	1485	990	495
12	2475	1485	990	495
Total System Costs: Fluid and Power System				
Case	Continuous Flow	12 Hr/Day Flow	6 Hr/Day Flow	2Hr/Day Flow
1	11365	6910	4435	2950
2	4111	3121	2626	2131
3	4219	3229	2734	2239
4	4500	3510	3015	2520
5	9010	5545	4060	3070
6	4444	3454	2959	2464
7	5539	4549	4054	3559
8	7706	6716	6221	5726
9	10814	6854	4874	3389
10	4984	3994	3499	3004
11	6161	5171	4676	4181
12	8831	7841	7346	6851

Table 3 presents the costs necessary to acquire adequate components for each system, it does not include the cost of labor to install the system. It also does not include the cost of the reservoir or any control system to maintain the reservoir at any particular level. As far as operating costs are concerned, there should be very minimal to no operating cost required. The solar panels may require occasional clearing of debris or particulates, but other than that there are no wear items comprising the system to influence operating costs or maintenance. The pipe costs were determined from *AF Supply* and *Grainger Industrial Supply.*

Conclusions and Recommendations:

Overall, Case 2 is the cheapest option. However, if a large amount of run time per day is required, i.e. continuous or 12Hr/Day flow, then Case 10 may be worth the additional investment, as it is much more corrosion resistant and will likely have a significantly longer lifespan. It may even be worthwhile to do a combination of the two, utilizing the galvanized pipe for the section from the ground to the well and cast iron for the remainder of the system. This is because it is much more labor intensive to replace the pipe from the ground to the well than it is to replace the pipe above ground. Tables 1-3 should be utilized to determine what the best fit is for each particular application.

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