FEASIBILITY OF USING SOLAR ENERGY FOR IRRIGATION PUMPING

by

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ABSTRACT

Solar powered pumping is technically feasible. However, solar energy intensity is variable and its collection requires high capital investment. Present production methods might require modification for most economic use of solar energy. Various irrigation and pumping practices are examined to determine those most compatible with use of solar power.

The tentative conclusion of the study is that solar energy usage is most economical for driving pumps only during sunlight hours and where pumping requirements are uniform throughout the year. Solar energy is a more costly source of pumping power than electricity or natural gas.

INTRODUCTION

Electricity costs have risen dramatically during the past three years and natural gas shortages portend curtailment. Where water is obtained from wells as much as 90 percent of the energy input for irrigated crop production is used for pumping. Arizona crop production is completely dependent on irrigation. Forty-eight percent of the cropland is irrigated with groundwater and another 34 percent is irrigated with a combination of ground and surface water.

Solar energy is a potential source of power for irrigation pumping and could reduce fossil fuel demands. However, solar energy is diffuse and available only during part of the day. Its intensity varies seasonally and from day to day with changes in atmospheric conditions. This paper assesses the technical and economic feasibility of using solar energy to drive irrigation pumps and discusses changes in pumping and irrigation practices which might be required with solar energy usage.

SOLAR POWER GENERATION

The conversion of solar energy to mechanical motion can be accomplished in a number of ways. Solar energy can be captured and converted to electricity by photovoltaic cells. These cells presently provide power for use in satellites and other remote locations. Though very promising, a production technology breakthrough may be required for solar cells to become an economic energy alternative for other applications (Kaplan, 1975).

Solar energy can also be collected as thermal energy, converted to mechanical energy and used to drive a pump or electric generator. SOFRETES, a French firm, has

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operational solar-powered pumping installations in Mexico and Africa (SOFRETES, 1975). General Electric (Eckard, Bond and Robertson, 1975) and other industrial concerns (Lindsley, 1976) have developed and are testing turbine and multi-vane expanders which convert low temperature thermal energy to rotary motion. Currently the largest power unit is believed to be the 30 KW turbine used by SOFRETES. Simple flat plate collectors can provide the required low temperature energy (perhaps as low as 65°C).

Higher temperature thermal energy can be converted more efficiently, an important consideration in solar energy utilization where collection is the major expense. Fresnel lens, parabolic reflector and multiple heliostat central receiver designs are some of the concepts being developed to concentrate solar energy and obtain temperatures as high as 600°C. Commercially available turbine generators could be driven by the steam produced by solar energy concentration.

PUMPING DURING DAYLIGHT HOURS

Irrigation pumps commonly operate continuously for several months during the peak irrigation period. For this situation, the use of solar energy as the sole power source would necessitate energy storage for use when solar energy is unavailable, pumping of larger quantities of water during hours of sunlight or a reduction in irrigation water use. Higher pumping rates could be obtained by increasing well output or drilling additional wells. Both methods require revised water management techniques. Irrigation water requirements could be decreased by improved irrigation efficiencies, crop substitutions and reduced acreages.

INCREASE OUTPUT OF PRESENT WELLS

Pumps are often selected to produce the maximum continuous discharge rate which does not exceed specified drawdown (difference between pumping and static water levels) limitations for a well in a given aquifer. Output of such wells cannot readily be increased, but possible methods of increasing the output of present wells are:

a. Increased pump capacity. If greater drawdown is permitted, well output could be increased by use of a higher capacity pump. Larger bowls or faster turbine speeds could provide the higher discharge rates. However, casing diameter limits possible changes and pumping efficiencies would likely be reduced. Pump replacement and greater pumping depth would both be required to increase present well output.

b. Increased well depth. A larger amount of aquifer could be made available for pumping if well depth is increased and the aquifer extends beyond the depth of the present well. However, a different pump would be needed to realize the increased well discharge rate and energy requirements would increase with the pumping depth.

c. Increased well diameter. Doubling the well diameter would yield only a small (approximately 11 percent) increase in its discharge rate, however, existing casings are prohibitively expensive or impossible to remove.

d. Well development. Rate of water movement from aquifer to well can be increased by well development to increase transmissibility of the aquifer in the region adjacent to the well. The development will yield little improvement in a "good" well or in a well which is gravel packed, but might improve transmissibility if a well has not been previously developed or has not been developed for a number of years.

ADDITIONAL WELLS

Additional wells offer a more promising method of compensating for the reduction in pumping hours and consequent reduction in daily well output due to use of solar energy and minimal energy storage. For example, three wells each delivering 1600 gallons per minute for six hours and 800 gallons per minute for two morning and two late afternoon hours would produce approximately the same amount of water per day as one well pumped continuously at 1600 gallons per minute.

To evaluate the potential for this modification, a computer program was used to compare the drawdown which might result from continuously pumping one well with that caused by pumping three wells during daylight hours. For the selected aquifer and continuous pumping of a single well at a rate of 1600 gallons per minute, drawdown was 34.5 feet at the end of the simulation. Maximum drawdown was 32.7 feet at the center well when three wells spaced 400 feet apart in a line were pumped during daylight hours in accordance with the schedule described above. The higher, periodic pumping did not result in excessive drawdown.

The fixed and variable costs of pumping water have been estimated for several typical wells, pumps and power sources in various locations in Arizona by Hathorn (1976). An example, Table 1, shows variable costs to be greater than fixed costs. Investment in well and pumping equipment would triple if three wells were required instead of one. The threefold investment increase would raise the fixed pumping cost to over $20.00 per acre foot of water. The cost of using solar energy for pumping must include additional required pumping and water delivery facilities.

Table 1. Cost of pumping in Cochise County, Arizona (Hathorn, 1976).

	Electrical Power $.0295/kwh	Natural Gas $.1178/therm
Fixed Cost (600 acre feet/yr.	7.14	9.55
Variable Cost (310 foot lift)	19.70	12.17
Total Pumping Cost	$26.84/ac.ft.	$21.72/ac.ft.

HANDLING HIGHER PUMPING RATES

Greater pumping rates during sunlight hours would create a need for methods and facilities for handling more water during these hours. Irrigation efforts during daylight hours would be increased or water storage provided to level out the delivery of irrigation water. Larger ditches would generally be required for the first method, reservoirs for the latter. Additional ditch construction or replacement of current ditches with larger ones would be costly. Where possible, well locations could be distributed to avoid the need for larger ditches.

Storage of the water discharged by two of the three 1600 gallon per minute pumps during daylight operations would require a storage volume of less than five acre feet. An earthen berm around a surface reservoir could provide the structure. Additional pumping lift would be required to fill the reservoir, but water could be discharged by gravity flow as desired. The reservoir would be subject to seepage and evaporation losses and control of these losses could be costly. Reservoir maintenance would include weed control measures.

CHANGE IN WATER REQUIREMENTS

Capital investments in wells and pumps, and also in solar energy collection equipment, increase with required pumping rates. A reduction in the required pumping rate is therefore highly desirable. Modest improvements in irrigation water delivery and pump-power plant efficiencies would yield direct benefits. For example, increasing water delivery and application efficiency from 60 to 70 percent and pump-power plant efficiency by a like amount would result in a 27 percent decrease in the irrigation power requirement. The reduced water requirement represents additional benefit.

A reduction in acreage would obviously result in decreased total pumping demand. However, well capital investment would be larger per cultivated acre. Certainly a change in the combination of crops to be irrigated could result in a reduction in peak pumping demand. The peak consumptive water requirement for the example crop combination shown in Figure 1 is estimated to be over 30 percent less than for cotton alone. A uniform pumping demand throughout the year is highly desirable when fixed costs constitute a major portion of pumping costs.

IRRIGATION MANAGEMENT

Intermittent water availability would cause changes in irrigation practices. Flood irrigation frequently requires water delivery for a period longer than sunlight hours in order to refill the soil root zone to its moisture holding capacity. Intermittent water delivery could reduce application efficiencies and increase water requirements. Irrigation labor needs might also be greater.

Sprinkler and drip irrigation systems are large capital investments. These systems are sized to meet maximum crop water requirements when used approximately at maximum capacity. Larger systems would be required if water were available for only a fraction of the day.

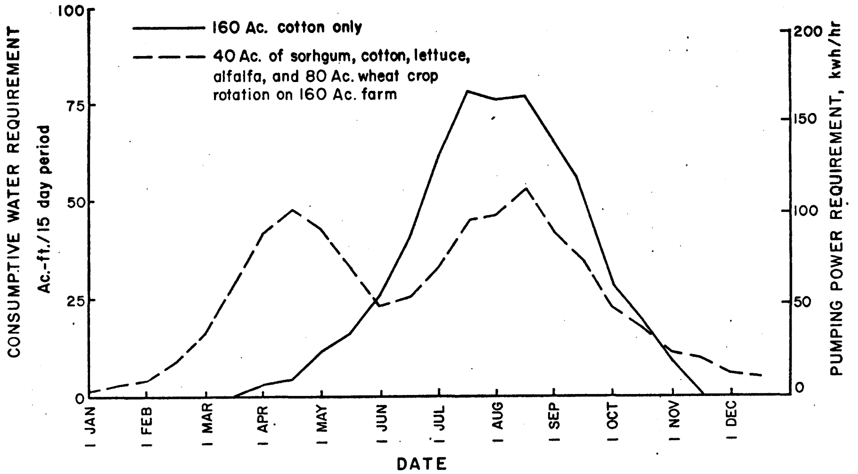

Figure 1. Consumptive water and pumping power requirement for two cropping systems at Mesa, Arizona. Running water level is 300 feet, water application efficiency is 70 percent and pump-power plant energy efficiency is 65 percent.

LARGE RESERVOIR

Greater utilization of solar energy collection and conversion equipment will yield lower unit energy costs. Solar energy intensity and crop water requirements are variable so energy supply and demand will frequently be unequal during the year. A reservoir which allows continuous daylight pumping and provides water for peak crop demands will minimize capital costs for wells, pumps and energy collection and conversion equipment. Reservoir construction costs will be great if a natural site is not available and reservoir maintenance will be necessary. Reservoir water losses will merit control when more costly than pumping.

CONTINUOUS PUMPING

Twenty four hour pumping would require energy storage for use during periods when solar energy is unavailable or utilization of alternative energy sources when solar energy is insufficient.

ENERGY STORAGE

Solar energy must be stored if it is to be used as the sole energy source for continuous pumping. Energy storage concepts being developed by various researchers include batteries, fuel cells, flywheels and thermal energy storage (Ramakumar, 1976).

Use of a storage system necessitates collection of sufficient energy during sunlight hours to power the pump and charge the energy storage system. For example, solar energy might be used directly for eight hours and energy from storage would supply pumping power for the remainder of the day. The collection equipment and storage system required for 24-hour pumping would be a large investment; one comparable to that required for the three well possibility described previously.

SOLAR PLUS SUPPLEMENTAL ENERGY

Solar energy might be used to power the pump only when directly available. A limited amount of energy storage, perhaps for one hour of use, would provide a buffer to counter small variations in solar input. One of several alternative energy sources could then supply pumping power for the remaining period. Coal, wood or oil could supply the thermal energy provided by solar energy during sunlight hours. A single system would be required for converting thermal to mechanical energy with this procedure. A burner would be the only additional item required in the energy conversion system. However, system operation would require some labor or mechanical input to handle the alternative fuel source.

Management might be easier if electricity were used to drive pumps when sunlight is unavailable. This method would be particularly attractive if off-peak electrical rates were available. Several persons have proposed that an attractive relationship would be solar powered pumping with excess solar generated power being sold to utilities when available, perhaps during peak demand late afternoon hours. The farm would in turn receive electric power for night time use at reduced rates.

UTILIZATION OF VARIABLE ENERGY

Lesser amounts of solar energy are available during early morning, late afternoon and cloudy periods. A pumping system requiring a minimum level of power for operation would not fully utilize low solar energy inputs, Figure 2. Energy storage can extend operational hours somewhat. Less costly pumping would result from use of pumps which could efficiently utilize the variable solar energy input.

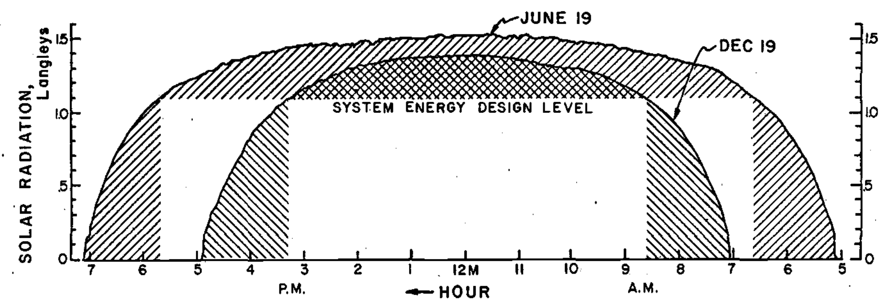

Figure 2. Variability in solar energy intensity received on a clear day.

An energy conversion system which utilizes variable input energy levels to produce corresponding variable levels of shaft power is being investigated by Texas Tech University researchers (Strickland, 1976). Turbine pump power requirements and output are less at reduced speeds. Maximum pump efficiency is generally obtained only for a narrow range of operating speeds. However, some pumps are available for efficient pumping with variable speed operations.

SOLAR POWERED PUMPING COSTS

Many solar components required in a pumping installation are not available commercially. A comparison of solar powered pumping costs with costs using other energy sources can only be estimated using assumed future solar equipment costs. Alcone (1976) estimates the cost of pumping with solar energy at $60-$100 per acre foot. His estimate assumes a thermal energy conversion efficiency of 10 percent, 10 percent interest with a 20-year capital recovery period, solar collector costs of $5 to $20 per square foot, and 100-200 foot pumping lift. The cost would be about 25 percent less if off-peak electric energy were used along with solar energy.

The capital investment in equipment to collect solar thermal energy and convert it to mechanical energy has been projected by other researchers to be $1000/KW electric (Lipps and Hildebrandt, 1976). Assuming operating costs of $10,000 per year for a 100 KW plant, 10 percent interest with a 20 year capital recovery period, pumping fixed costs of $10 per acre foot and uniform yearly pumping demand for over 200 days, solar powered pumping would cost over $50 per acre foot of water. This cost would be competitive if electrical rates were approximately two times and natural gas rates three to four times those used in computing costs in Table 1. Pumping costs of this magnitude would result in uneconomic production of many crops in Arizona.

DISCUSSION

Solar powered pumping is technically feasible. However, more efficient, lower cost energy collection and conversion are required for solar energy to compete with alternative energy sources today.

Continuous pumping would require energy storage or use of another energy source in conjunction with solar energy. Large, costly energy collection and storage systems would be required with use of solar energy alone. Off-peak electrical power or another energy source could be used with solar energy and provide less costly energy for continuous operation.

Major changes in current irrigation and pumping practices would be required if pumping was possible only when solar energy is available. Higher pumping rates might be required during periods of solar energy availability. Revised irrigation practices might also be required to reflect the sun dictated schedule. Use of a reservoir would prevent the need for daily matching of pumping and application rates.

Solar powered pumping costs would be largely due to capital investment. Uniform yearly water production would thus be least costly. Projected solar powered pumping costs would result in uneconomic production of several Arizona crops.

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