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THE 50-HORSEPOWER SOLAR-POWERED IRRIGATION FACILITY LOCATED NEAR GILA BEND, ARIZONA

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ABSTRACT

The operation of the 50-horsepower solar-powered irrigation facility near Gila Bend, Arizona over three years demonstrates the technical feasibility of solar-powered pumping. The Rankine cycle facility was built using 1976 technology. The requirement now is to use the technology that has been developed over the last four years to design a facility specifically for the irrigation farmer. Considerations to meet his needs and to demonstrate whether solar thermal conversion is a potentially viable application for pumping irrigation water in the United States are suggested.

INTRODUCTION

The initial program to develop the 50-horsepower solar-powered irrigation facility was funded at Battelle Memorial Institute by The Northwestern Mutual Life Insurance Company as one of several programs undertaken to accelerate the development of practical applications of solar energy.

The installation is on a 76,000-acre ranch west of Gila Bend, Arizona. The ranch represents an agricultural investment in one of this country's most arid regions where intensive irrigation is required to produce crops on the 25,000 acres that are irrigated.

The solar irrigation pumping system serves to return tail water from a collection sump to concrete lined distribution ditches. Water supplied to the irrigation system from a number of deep wells is applied to the fields from the distribution ditches by siphons in an amount approximately 10 percent in excess of that required by the crop; the resulting 10 percent runoff is recovered from the graded fields in a network of tail water ditches. The solar irrigation pump returns the tail water, which collects in a sump, to irrigation ditches servicing an area of approximately 5000 acres. The lift from the tail water sump to the distribution ditches varies daily, ranging from 7 to 12 feet.

In 1975 when the design of the facility was initiated, the following were guidelines:

(1) Select off-the-shelf equipment or equipment that was as near to off-the-shelf as possible

(2) Take every advantage of available technical information with proper exercise of experience and judgment

(3) Design a system to produce 50 horsepower but include the potential for applying the same design practices to scale up to 250 horsepower

(4) Include in the design the potential for operating the system in remote locations with only minor modification.

The thrust of these guidelines was that our program was not to be a research effort; it was a development and application effort.

System definition, design work, component selection, procurement, assembly, testing, and installation were completed in about 18 months; the system was dedicated in April, 1977. The basic components of the system are shown in Figure 1.

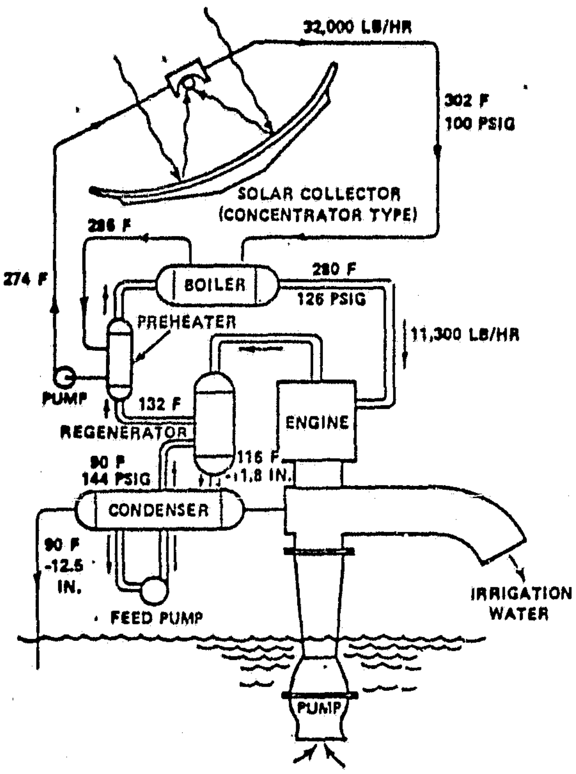

FIGURE 1. A SCHEMATIC OF THE SOLAR-POWERED IRRIGATION SYSTEM: 1977

The figures are design values.

The collector field (5785 sq ft) heats the water, which in turn is used to flash the working fluid (R-113) to drive the Rankine cycle turbine at a maximum speed of 30,500 rpm; this is then geared down to 1755 rpm. The 50-horsepower system can deliver a maximum of 10,000 gpm.

In this paper, there is no attempt to cover all of the activities in the three years of operating the facility and making modifications to it. The purpose is to highlight some observations dealing with the pragmatic use of solar power in a particular agricultural application.

OPERATIONS

The system was operated for a total of 800 hours during part of the 1977, 1978, and 1979 irrigation seasons. On several occasions the water pumped exceeded 9000 gpm over short periods and an average of 7000 gpm for several entire solar days.

Collectors

When the collectors were new, well-focused, and tracking under bright sun conditions, they regularly delivered 48-52 percent average efficiency (design was 55 percent). After several months, and several problems which included the overtemperaturing of two absorber tubes, typical efficiency dropped to 46 percent.

To reduce convection losses, the absorber tube/receiver assembly was originally fitted with half-round sections of glass set into a seal. Dirt and dust which built up on the outer surface, though serious on its effect on operations, could be readily removed. However, within one month, the dust buildup on the interior surface of the glass was such that the covers had to be removed to be cleaned. The attendant problems with cleaning the glass -- removal, replacement, seal alignment, breakage -- immediately created an incentive to operate without the glass. We ran some tests comparing adjacent rows with and without clean glass covers; we were not able to measure individual flow rates. On the basis of our tests we found there was actually an increase in ΔT without the glass covers. The results would have been even more significant if the glass covers had been just a little bit dirty on the inside or the outside. We discontinued the use of the glass because in our system -- operating around 300 F -- it was far from cost effective to operate with them.

Dust is a normal environmental feature in Gila Bend. The dust, whether from dust storms, dust devils, or agricultural operations will collect on reflector surfaces. From a practical viewpoint the dust -- at least our dust -- did not reduce performance nearly as much as one would think. In the first year of operation the reflecting surface appeared very dusty after about one month -- particularly when viewed from a flat angle. The reflectors were immediately washed. There was no noticeable difference in the energy output of the field before and after washing. The field was washed twice more during 1977 with the principal difference still being aesthetic. From August 1977 through the five months of operation in 1978 and until August 1979 the collectors were not washed again. By this time the dust accumulation was such that performance was improved by washing. It will be significant to the farmer to know what the washing requirements are for his application. Washing is expensive; "excess" dirt accumulation will affect output. The farmer will want a definition of "excess" that he can use.

During 1978 a number of changes were made in the receiver assemblies. Some of the coatings on the receiver tubes appeared to have degraded; powdering and flaking were evident. A new receiver assembly design was available which had overall system improvement as well as improved thermal features. Combinations of old coatings, new coatings, black chrome, old housing, and new housings were a part of the 1978 and 1979 system. The performance of the various combinations of components does not appear to be markedly different, but detailed examination would have to be made to evaluate the efficiencies of the individual rows. If, as we suspect, there are only modest differences in efficiencies, the long-term effect of this in terms of initial costs and maintenance costs is significant.

Generally, the collectors appear to be holding up fairly well. There is one place on the reflector side where the metal backing is breaking away from the honeycomb core material. The manufacturer has looked at the separation; it is his judgment it is the result of a manufacturing error rather than degradation. Additionally, there are several places where the aluminized reflector surface is not adhering to the substrate as it should. Most of this, which is new this year, is occurring at seams but there are several places where there is some delamination in the middle of a panel. This degradation does not represent a large percentage of the total surface area. It does, however, represent a potential maintenance cost either in terms of repair or replacement.

The remaining components of the collectors do not appear to be degrading in any way that affect performance or require maintenance.

Tracking

The subsystem that has caused the greatest problem is row tracking. It was, and still is, difficult to maintain consistently accurate tracking in conditions of changing cloud cover and haze. We have made modifications to our On/Off switching to incorporate semiproportional control on the motor speed and have replaced the mechanical relays with solid-state switching devices. Other improvements can be made and systems newer than ours offer substantial improvements. One problem with the newer systems is that the costs are going in the wrong direction.

Heat Exchangers

There is one feature of the Gila Bend facility on which we have little information. Data is available to calculate the performance of the heat exchangers — boiler condensor, regenerator, and preheater; the calculations made in 1977 and for part of 1978 indicated design or near design performance. Information is not available, however, on what is happening to the inside surfaces of the heat exchangers. This information must be developed to determine the maintenance requirements and to provide a design for the components that will enable the maintenance to be carried out.

RECOMMENDATIONS

The Gila Bend facility is basically a 1976 design. It was designed to demonstrate an application using state-of-the-art equipment. It has demonstrated that application. What is required now is an update to use the current state of the art (which is significantly advanced over 1976) and design an overall facility which will best fit the needs of the irrigation farmer.

It has yet to be demonstrated for the United States market whether the use of solar thermal conversion is (or is not) a viable application when the principal use is for pumping water. To date, most, if not all, of the demonstration systems have been built by engineers to be run by engineers. The real world need will be to deliver a system that is acceptable to the farmer in terms of meeting his operating and maintenance requirements . . . and particularly because of today's interest rates — first cost. A demonstration unit should be built with the following in mind.

(A) Components used must have the potential for significant cost reduction.

(B) The farmer wants water "on demand" day or night. The primary pumping will be by electric motor (or gas or diesel engine). Solar power, when available, will be used to reduce other forms of power consumed. This approach is equally applicable to low lift, shallow well, and deep well requirements. Furthermore, the potential solar output does not need to match the power requirements of the pump motor; the solar power portion can be substantially smaller and still be effective.

(C) The collector operating temperature needs to be examined carefully. The pros and cons of temperatures requiring glass covers for absorber tubes need to be examined in terms of field use by the farmer, not laboratory use by the engineer.

(D) A sump application, such as the one at Gila Bend, is less desirable than an application on a well. The water from a well which will be diverted for the condensor cooling water is better than the water from a sump for two reasons:

(1) The temperature of the well water is lower and does not have the temperature variation over time that is characteristic of sump water.

(2) The well water does not have the solid debris characteristic of sump water.

(E) Tracking systems must provide the capability to follow the sun accurately when it can provide thermal inputs to the system. As mentioned before, systems are improving but costs are not. There have been many advances in the last four years in control technology and timing devices. For this specific application, a detailed examination should be made of the relative advantages of tracking the sun on the basis of where it actually is and where it is calculated to be.

(F) The master control system needs not only to start and stop the system under normal conditions but also to provide diagnostic information to the user for causes of shutdown or preventable falloff in performance. This suggests a well-conceived instrumentation and signaling system.

(G) In the design process, consideration must be given to how the farmer wants to operate and maintain his water pumping system.

(1) When the pump is running, the solar portion of the unit should start automatically when there is sufficient energy from the sun; conversely, it should shut itself off automatically.

(2) The system should run automatically and reliably without the need for an operator in attendance. One or two checks a day by the farmer (similar to the checks he currently makes on his motor driven pumps) should be sufficient.

(3) The levels of skills required to operate and maintain the system should be little different than those currently employed. It is reasonable to assume that one week or less of training would provide the level of skills required for maintenance.

The foregoing does not necessarily define a large-scale system. In fact, quite the opposite may be true. For demonstration purposes, a 25 to 50-horsepower system could be used, coupled with a well-head pump.

The two existing systems that have any similarity to the system suggested are circa 1976 technology. With the advances that have taken place since, then, not only in solar technology but also in control technology, there is now the opportunity to really test the viability of solar thermal conversion for pumping water in U.S. irrigation operations.