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SOLAR TECHNOLOGY APPLICATIONS: A LITERATURE REVIEW OF
SOLAR THERMAL POWERED IRRIGATION SYSTEMS

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SOLAR TECHNOLOGY APPLICATIONS: A LITERATURE REVIEW OF
SOLAR THERMAL POWERED IRRIGATION SYSTEMS

INTRODUCTION

There is a growing need for solar thermal powered pumps in many sun-rich but fuel-poor parts of the world for irrigation and stock-watering applications. In the western United States, for example, solar energy has the potential of making irrigated farming independent of fossil energy, and to aid in the production of more food for the nation in the future. In the western states, a wholly irrigated farm produces nearly seven times more crop value per acre than an unirrigated farm. It is estimated that replacement of over 160,000 natural gas powered irrigation wells with solar powered pumps in California, Arizona, New Mexico and Texas would create energy savings of 1.4×10^{14} BTU's or 1.4×10^{11} cubic feet of natural gas annually (1969).

On a national basis, census data indicate that irrigated agriculture provides 15% (\$3.1 billion) of U.S. agricultural exports and 20% of the value of the total national agricultural output. Approximately 30% of the U.S. cropland is dedicated to producing export foodstuffs, and 10% of the U.S. cropland is irrigated.

Irrigated farms in the seventeen western states, which represent over 80% of the irrigated land in the U.S., produced 20% (\$9 billion) of the total U.S. farm products in 1969. On the average, about half of the value of agricultural products sold in these States derives from irrigated land. Arizona, California, Texas, and New Mexico contain 35% of the irrigated land in the U.S. and in 1973 agricultural products valued at more than \$50 million were produced from groundwater irrigated land in New Mexico alone.

Presently, the farmer has little choice in an alternative energy source to power his pumps and must turn to even more expensive fossil fuels (diesel oil) or electricity. As gas prices rise and the supply available for irrigation purposes decreases, solar powered irrigation could provide a clean, alternative source of energy for the nation's food production industry.

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This report is a single reference source which summarizes published information on solar thermal powered irrigation systems. It is a compilation of literature references and a survey of on-going work in this field. Much of the material here outlined is tentative, rapidly changing, and highly variable in time and place. The following information should therefore be considered a guide rather than a set of specifications and will be updated as additional information and references appear in the literature.

Where large tracts of land are not available for solar power plants, solar energy can be converted to electrical energy by means of photoelectric or thermoelectric cells. Currently, because of the high cost of fabricating panels containing these units, applications are limited to small devices such as satellite transmitters and receivers, hearing aids, clocks, etc., and will not be reviewed in this report. However, as costs are reduced through more extensive R&D in this technological area, conversion of solar energy into mechanical power by these techniques should occur on a much larger scale.

BACKGROUND

Solar heat can, in theory, be readily converted to mechanical power for direct use in water pumping and for further conversion to electricity by means of piston and turbine engines. This general field of technology has, in fact, been the subject of many historical attempts to devise heat engines from solar energy before the advent of photoconversion technology.

The utilization of solar energy to lift water for irrigation was first described by the French engineer Solomon de Caux in 1615. Improvements continued over the years up to World War I, after which there was a gap in research efforts because of the ready availability of cheap fossil fuels. Today, a modern system consists of a solar collector field, an energy storage facility, solar engine, water-pumping equipment, controls, and a water-storage area. Figure 1 shows a schematic diagram of a system that is typical of the unit being developed by the Energy Research and Development Administration (ERDA).

In operation, a preheated heat transfer fluid is pumped into the collector field. Solar energy from the 6,720 sq. ft. of sun-tracking parabolic trough collectors heats the fluid to 420°F. A thermal control valve then opens to allow the fluid to flow either to a thermal storage tank or to the boiler/heat exchanger.

In the boiler/heat exchanger, the transfer fluid is heated to a gaseous state, expands, and reaches a temperature of 325°F and a pressure of 220 psi. The heated, high-pressure gas drives the turbine which in turn operates the irrigation pump. In this closed-loop system, the heat transfer fluid, exhausted from the turbine, is then circulated through a regenerator heat exchanger, a condenser heat exchanger, then back through the cooling side of the regenerator heat exchanger. It is then returned to the boiler/heat exchanger as a liquid.

The heat transfer fluid flows from the boiler/heat exchanger either back to the thermal storage tank or to a mixing tank. The mixing tank limits the inlet temperature to the solar collectors and aids in controlling temperature of fluid leaving the collectors.

The water is taken from the storage pond for actual irrigation by a conventional pumping system. The conventional pump operates on demand to allow different types of irrigation equipment to be tested. When the system is not operating the irrigation pump, it can generate electric power and provide the heating needs for a greenhouse, a fish farm, a crop dryer, and a farm house.

FIG. 1

BIBLIOGRAPHY AND SURVEY OF ON-GOING WORK

1. "The Utilization of Solar Heat for the Elevation of Water,"
Scientific American, October 3, 1885, p. 214.

SUMMARY: The apparatus at Auteuil, France, raises over 300 gallons of water per hour from a depth of 65 feet using 350 square feet of collecting area.

2. Ericsson, J.

"Sun Motor,"
Harper's Weekly 31: 10 Jan 1887

SUMMARY: A review of John Ericsson's work in developing a sun motor for pumping applications.

3. Willsie, H. E.

"Experiments in the Development of Power from the Sun's Heat,"
Engineering News 61 [19], 511, May 13, 1909.

SUMMARY: A brief outline of the state of the art in the production of power from solar heat and the efforts made to commercialize sun power systems primarily for irrigation purposes.

4. Shuman, F.

"Sun Power Plant,"
Proceedings, Manchester Association of Engineers, Discussion Session,
1913-14, Manchester, England, p. 405-443.

SUMMARY: A review of the various sun power plants that have been built to 1914.

5. Acherman, A. S. E.

"The Utilization of Solar Energy,"

Journal of the Royal Society of Arts, p. 538, April 30, 1915.

SUMMARY: A chronological review of the history of solar thermal engines and their applications. A complete reference list of previous work to date.

6. Molenaar, A.

"Water-Lifting Devices for Irrigation,"

Food and Agricultural Organization, United Nations, New York, 1956.

SUMMARY: A review of the application of water-lifting devices for irrigation purposes.

7. Mathur, K. N. and M. L. Khanna

"Application of Solar Energy to Small Scale Industries,"

Solar Energy 1 [1], January 1957, p. 34.

SUMMARY: The application of solar energy to the raising of water for irrigation and domestic purposes, to cooking and to power generation are discussed briefly; and the concentration of sugar cane juice and palm juice are examined in some detail. Results are tabulated for experiments on the evaporation of cane and palm juices conducted in the Laboratory and in the open fields, using solar concentrators with 9 in. square plane mirrors, designed by Gardner. Field experiments showed an efficiency of 30 percent, but it should be possible to reach 50 percent. The capital cost of the unit can be recovered in fuel savings within three seasons.

8. Hsu, S. T. and B. S. Leo

"A Simple Reaction Turbine as a Solar Engine,"

Solar Energy 2 [3-4], July-October 1958, p. 7-11.

SUMMARY: This article describes the design of a simple reaction turbine operating on saturated low pressure steam that could be generated by a solar boiler. The turbine was developed primarily to obtain a small power unit for irrigation purposes. Tests were therefore performed with the combination of turbine and a centrifugal pump. Horsepower curves and rotational loss curves are shown, and a comparison is also presented with five other small prime movers of varied design.

9. Dannies, J. H.

"Solar Water Pumping,"

Solar Energy 3 [1] 29 (1959).

SUMMARY: The left-way cyclic process is described for obtaining water out of air using two working methods. The first one delivers drinking water out of air without any service, maintenance, etc. The second method requires opening a cover above the absorbent during the evening. In Central Europe, the water quantity obtained with the second procedure corresponds to 0.90 to 1.70 mm daily rainfall on a yearly average whereas in the North Sahara, about 150 to 200 miles off-coast, it is about 10 percent more. Water delivery from the first procedure is less.

10. Jenness, James R., Jr.

"Some Considerations Relative to a Solar-Powered Savery Water Pump,"

Solar Energy 5 [2] 58 (1961).

SUMMARY: The primitive Savery steam engine is described which could be adaptable to mass production at low unit cost. In spite of its low efficiency it may be useful as a solar-powered low-lift water pump.

11. Jordan, R. C.

"Conversion of Solar to Mechanical Energy,"

An Introduction to the Utilization of Solar Energy, A. M. Zarem
and D. D. Erway, eds., New York, McGraw-Hill, 1963, Ch. 7, p. 125-152.

SUMMARY: A water pump, developed in Italy, is operated with a standard Rankine vapor cycle heat engine using sulfur dioxide as the working medium. Sulfur dioxide is vaporized in the flat-plate collector and this vapor is used to drive the engine. The power so developed may be used to generate electricity or to pump water. This Somor 2.5 horsepower solar engine system is manufactured by the Societa Motori Recuperi of Lecco, Italy.

12. Girardier, J. P. and H. Masson

"Solar Motors with Flat Collectors,"

Annales Des Mines: 33-8 (September 1964).

SUMMARY: An experimental solar motor is described which drives a pump lifting 8 to 10 liters water per minute from a depth of 13 meters.

The construction of a more efficient pump is also described. It has a collector of 300 m^2 capable of supplying about $40 \text{ m}^3/\text{hour}$ of water lifted from a depth of 8 to 10 m. This quantity of water represents the approximate daily requirement of a community of 500 persons.

13. Gilleland, F.

"Eneas Solar Water Pump,"

Sun at Work 10: No. 4, 12-14 (1965).

SUMMARY: A description of the pump capable of raising 150,000 gallons of water per day a distance of 40 feet using 175 square feet of collector area; sufficient for the irrigation needs of 100 acres.

14. Masson, H. and J. P. Girardier

"Motors with Flat-Plate Collectors,"
Solar Energy 10 [4] 165 (1966).

SUMMARY: An experimental solar motor has been operating since August 1962 which drives a pump lifting 8 to 10 liters water per minute from a depth of 13 meters.

This experiment being successful, the construction of a more efficient pump is also described. It has a collector of 300 m^2 capable of supplying about $40 \text{ m}^3/\text{hour}$ of water lifted from a depth of 8 to 10 m. This quantity of water represents the approximate daily requirement of a community of 500 persons.

15. Shergill, S. S. and R. P. Morgan

"Analysis of an Oscillating Engine for Power Production
Based on the 'Drinking Bird' Principle,"
Proceedings of the Fourth Intersociety Energy Conversion Engineering
Conference, September 25-26, 1969, Washington, D.C.

SUMMARY: A hypothetical oscillating engine was analyzed which works on the "Drinking Bird" principle. Calculations were performed for a toy device and for a larger engine suitable for pumping water. Applications are discussed for use of the engine as a small power source in developing countries.

16. Girardier, J. P. and H. Masson

"Utilization of Solar Energy for Lifting Water,"
Preprint, 1970 International Solar Energy Society Conference,
Melbourne, Australia, March 2-6, 1970. Paper No. 6/116.

SUMMARY: The paper discusses solar engine installations with fixed, plane collectors. The results obtained and the economics of the systems are discussed in detail. One installation delivered $6.8 \text{ cubic meters/hr}$ of water against a head of 34 meters using 88 square meters of collector area.

17. Beale, W., J. Rauch, R. Lewis and D. Muley

"Free Cylinder Sterling Engines for Solar Powered Water Pumps,"
Paper presented at the ASME Winter Annual Meeting, Washington, D.C.,
November 28 - December 2, 1971.

SUMMARY: Test results are given of a solar water-pump system. The water-pump system has demonstrated 10 w of delivered water power from a 0.3 sq m Fresnel lens at an engine absorber temperature of 460 C.

18. Swet, C. J. and H. G. Fox (John Hopkins University, Silver Spring, Maryland)

"Low Head Solar Water Pumping," Direct Use Without Intermediate Heat Engine, U.S. 8th Intersociety Energy Conversion Engineering Conference, Philadelphia, Pennsylvania, August 13, 1973. American Institute of Aeronautics and Astronautics, New York, 1973, A. H. Smith (Editor).

SUMMARY: A representative device is described that pumps water by the direct pressure of solar heated air. Cost and producibility are discussed, and the results are presented of a parametric design and performance study.

19. Maumouni, A.

"Energy Needs and Problems in the Sahelian and Sudanese Zones: Prospects of Solar Power," Ambia Volume 2 (6) p. 203 (1973).

SUMMARY: The author points out that solar energy water pumping devices should play a very large role within the frame of a balanced, general energy policy. A discussion is presented of the experimental Masson-Girardier solar engine for pumping water located near Niamey, Niger.

20. Salieva, R. B.

"Some Generalizations of Sample Water-Supply Calculations from Solar-Powered Pumping Plants,"

Applied Solar Energy, Vol. 10, No. 1-2, 1974, p. 67-70, Translation.

SUMMARY: The relationship between planned water consumption and water supply is investigated for a solar pumping system with stochastic variation in the solar radiation.

21. Salieva, R. B.

"Agricultural Calculations for Solar Pumping Systems,"

Geliotekhnika 11 [3-4] 112 (1975).

SUMMARY: The relationship between planned water consumption and water supply is investigated for a solar pumping system with stochastic variation in the solar radiation.

22. "Will Sun Power Water Deserts"

Engineering, p. 887, November 1975.

SUMMARY: A Fluidyne pump is described that can deliver water at 50 to 100 gal/h powered only by solar energy. The extremely simple design is self-starting and cycles automatically: air is displaced between a hot zone and a cold zone, rhythmically expanding and contracting. Pressure reversals on the output tube and the action of two non-return ball valves produce a pulsed delivery. Delivery rates are reported to be 50 to 100 gal/h at a lift of 8 ft.

23. Fiatte, F. and M. Clemot

"Water Pumping - A Practical Application of Solar Energy,"

Presented at COMPLES/UPM International Conference on Heliotekhnique & Development, Dhahran, November 2-6, 1975, Vol. 2, p. 331.

SUMMARY: Various solar water pumping installations are described, which are operating in Africa and Latin America.

24. Meinel, M. P.

"Solar Energy Applications to Water Pumping and Agriculture,"
Presented at COMPLES/UPM International Conference
& Development, Dhahran, November 2-6, 1975, Vol. 2, p. 307.

SUMMARY: Several low temperature, solar water pumps are described which are under evaluation in the Sonora desert. An adapted collector is described which has applications to crop drying, house heating, and animal shelter heating.

25. Rao, D. R. and K. S. Rao

"Solar Water Pump for Lift Irrigation,"
Solar Energy 18 405 (1976).

SUMMARY: Two types of solar water pumps have been developed and tested for lift irrigation. The pumps have no moving parts except for the check valves and no auxiliary power source or technical skill is required to run the pumps.

26. Battelle Memorial Institute, Pacific Northwest Laboratories Bulletin, 1977

"Solar Powered Pump at an Advanced State,"

SUMMARY: A 50 horsepower solar irrigation pump is to be installed on the Northwestern Mutual's Gila River Ranch, a 76,000 acre agricultural facility southwest of Phoenix, Arizona. The pump system includes a solar collector, a heat transfer fluid system and a vapor expansion engine.

27. Alvis, Robert L. and Jerry M. Alcone

"Solar Powered Irrigation System,"
Sandia Report, SAND 76-0358, September 1976.

SUMMARY: A solar powered irrigation system is to be constructed on a working farm in the Estancia Valley of New Mexico. The system is to demonstrate that solar power can power an irrigation system and the performance data generated will be used to predict solar powered irrigation system

27. SUMMARY: continued

feasibility on both a local and a regional basis. The program is jointly sponsored by ERDA and the State of New Mexico with New Mexico State University and Sandia Laboratories performing the duties of the program.

There are two system design approaches being considered. One, a low temperature system using flat-plate collector technology and its associated reduced cycle efficiency and two, using focusing-tracking collector technology and its associated higher cycle efficiency. This request is for engine proposals for either (or both) low temperature (420⁰F) peak temperature heat engine. The performance of each engine proposed will be analyzed with proposals received from collector suppliers in determining the best performing system per system cost. Only one system approach will be finally selected and purchased. The heat engine will consist of the necessary equipment to take thermal energy from a thermal storage reservoir, utilize a small amount of electrical energy for pumping and control, cool the condenser with the irrigation water pumped, and produce 25 shaft horsepower for pumping water. The engine will be directly coupled to a turbine irrigation pump through a right-angle drive and drive shaft and be engaged or disengaged by a manually operated clutch. The clutch is considered part of the engine. A total of 6,720 ft of collector area are planned and the pumping rate will be 700 gpm at a depth of 111 feet.

28. Alcone, Jerry M., Sharla G. Vandervender and Robert L. Alvis

"Solar Irrigation Program Plan,"

Sandia Report, SAND 76-0594, November 1976.

Sandia Report, SAND 77-0110, January 26-27, 1977.

SUMMARY: These reports describe the ERDA solar irrigation program plan through FY79. The goals of the plan are listed, the participants named, and their responsibilities outlined. ERDA has the program responsibility; ERDA field offices, the contractual

28. SUMMARY: continued

responsibility; and Sandia Laboratories, the technical direction responsibilities. This document is intended to be used as a program guide for accomplishing the goals.

29. "Sun Pumps Water, Too,"

San Jose Mercury, Wednesday, February 9, 1977, p. 61.

SUMMARY: Acurex Corporation, Aerotherm Division, Mountain View, has been chosen as one of three firms to come up with a preliminary design for a solar system to pump irrigation water. Acurex, which has already designed a system for installation at San Luis de La Paz, Mexico, is planning to place the system in southern Arizona by the end of 1979.

30. "Irrigation Using Solar Energy,"

NASA Literature Search Number 34584, February 18, 1977.

SUMMARY: Citations arranged by Accession Number from 1962 to February 18, 1977. Contains 24 citations.

31. Null, E. R.

"Solar/Stirling Power Plant Applications to Urban Water Pumping," Paper presented at the Conference, Toward Incorporation of Alternate Energy Sources Into the National Energy Policy, May 2-4, 1977, Palm Springs, California.

SUMMARY: The Desert Water Agency, in association with Aeronutronic Ford, has developed a Solar/Stirling Engine Deep Well Water Pumping Project for general water pumping in the water service industries including irrigation and wastewater. The project involves collecting light energy with tracking mirrors, concentrating light energy to heat energy in a cavity receiver, transmitting the heat energy through a eutectic heat pipe and heat storage system to a Stirling

31. SUMMARY: continued

(external heat) Engine, converting the heat to mechanical energy, and driving a deep well pump through a right-angle gear drive.

The electrical pumping units currently installed in the Agency's wells, which will be replaced by the solar system, lift water from 250 to 400 feet below ground and raise it to as much as 100 feet to 200 feet above ground. Average pumping heads approximate 500 feet.

Preliminary information indicates that urban pumping requirements for the ten million or so people in Southern California alone require between one-half and one billion kilowatt hours of electrical energy. Perhaps 25% of the plants could be converted to solar energy with the remaining 75% continuing on conventional electrical systems because of non-solar limitations.

32. "Arizona Solar-Powered Irrigation System Delivers 10,000 Gallons of Water Per Minute,"

Solar Energy Intelligence Report, May 21, 1977, p.88.

SUMMARY: Northwestern Mutual Life Insurance opened what it calls the world's largest solar-powered irrigation system on April 25, 1977 in Gila Bend, Arizona. Developed by Battelle Memorial Institute in a cooperative program with NML, the system has a 50-horsepower pump capable of delivering up to 10,000 gallons of water per minute. According to Battelle, the system will be able to deliver up to 5.6 million gallons of water within ten hours.

PATENTS

1. Tellier, C.

"Equipment for the Activity of a Pump Apparatus for Solar Heat,"
German Patent No. 34749; August 15, 1885.

SUMMARY: A pump is described for lifting water in irrigation systems or for solar home heating and cooling installations.

2. Bonaventura, Filiberto A. and Donald E. Plympton

"Solar Energy Pump,"
Patent No. 2,688,922; September 14, 1954.

SUMMARY: This patent relates to a solar energy pump, more particularly for use in pumping water or other liquids by means of solar energy.

3. Bonaventura, Filiberto A. and Donald E. Plympton

"Solar Energy Pump,"
Patent No. 2,688,923; September 14, 1954.

SUMMARY: This invention relates to a solar energy pump, more particularly for well-water pumping.

4. Glickman, Leonard

"Sunshine Hydro Electricity,"
Patent No. 3,903,700; September 9, 1975.

SUMMARY: A solar heat generator is reported having a plurality of pipes therein carrying an expansible fluid supplied from a fluid storage tank to a motor. The fluid is heated in the solar heat generator by the sun's energy and expands and pressurizes to drive the motor which, in turn, drives a water pump for pumping water from a lower reservoir to an upper reservoir.

5. Thureau, Pierre and Michael Bremont

"Pumping System Using Solar Energy,"

Patent No. 3,937,569; February 10, 1976.

SUMMARY: A pumping system is described comprising a pumping unit formed by a motor and a pump and adapted to raise a liquid from an underground level to a utilization level. The vaporizable fluid flows in a closed circuit between a solar evaporator and a condenser, the said motor being disposed in the outgoing branch between the evaporator and the condenser, and a circulator being disposed in the return branch. The motor comprises a motor chamber which is connected by an internal bistable distributor either to the evaporator when said distributor is in an intake state, or to the condenser when said distributor is in an exhaust state, said motor chamber being partly limited by a flexible wall free to move between an intake stroke end position and an exhaust stroke end position, the flexible wall triggering the changes of state of the distributor by reaching its two end positions.

6. Fletcher, James C.

"Solar-Powered Pump,"

Patent No. 3,972,651; August 3, 1976.

SUMMARY: A solar-powered pump is described which is particularly suited for intermittently delivering a stream of water. The pump is characterized by a housing adapted to be seated in a source of water having a water discharge port disposed above the water line of the source, a sump including a valved inlet port through which water is introduced to the sump, disposed beneath the water line, a displacer supported for vertical reciprocation in said housing, an air passageway extended between the vertically spaced faces of the displacer, a tipple disposed adjacent to the water discharge port adapted to be filled in response to a discharge of water from the housing, and a line so interconnecting the tipple and the displacer that the displacer is moved upwardly in response to a filling of the

6. SUMMARY: continued

tipple and moved downwardly once water is discharged from the tipple. Air above the displacer is expanded in response to solar energy impinging on the housing, transferred into pressurizing relation with the sump for forcing water from the sump.

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