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Application of Solar Energy to Continuous Belt Dehydration

B. J. GRAHAM

Trident Engineering Associates, Inc.,
Annapolis, Md.

A solar system utilizing a 553-m^2 (5950-ft^2) array of evacuated tube collectors has been designed to augment the heat supplied by natural gas to a Proctor & Schwartz continuous belt dryer used for processing onions and garlic at the Gilroy Foods plant in Gilroy, California. It has been calculated that the array, which contains 3216 evacuated tubes, will contribute 2.47 x 10^{12} J/yr (2340 MBtu/yr) to the dehydration process. The system is currently being installed and will be operational for drying in May 1979. This project was sponsored by the U. S. Department of Energy under Contract No. E-(40-1)-5119.

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INTRODUCTION

Large quantities of energy, particularly from natural gas, are consumed in the dehydration of food products. The dehydration of onions and garlic alone in 1975 consumed 4.0×10^9 MJ (38×10^6 therms) of energy, and the projected energy consumption for this process is 7.6×10^9 MJ (72×10^6 therms) by the year 2000(1). Solar energy resources make an ideal supplement to these energy requirements because the temperature demands are modest and because solar energy does not produce undesirable byproducts which are potential contaminants to food products. A system utilizing a 553 m^2 (5950 ft^2) array of evacuated tube collectors has been designed by Trident Engineering Associates to supplement the energy used in a Proctor & Schwartz continuous belt dryer for processing onions and garlic at the Gilroy Foods plant in Gilroy, California.

The Gilroy Foods plant has eight large continuous belt dryers, a portion of which is shown schematically in Fig. 1, which process onions and garlic around the clock, seven days a week, during a 183-day drying season. In a year, each dryer consumes enough natural gas to provide all of the heat requirements for nearly 500 homes. A dryer will use heat of different qualities and different forms along the various stages in the process line. Some heated air is immediately discharged after a single pass, some is recirculated, and some must be desiccated before it is used. All of these situations present different options as to how solar energy should be added to the system. An additional restriction is that the solar collecting system must be installed and tested during the off-season time and be running when the next drying season starts.

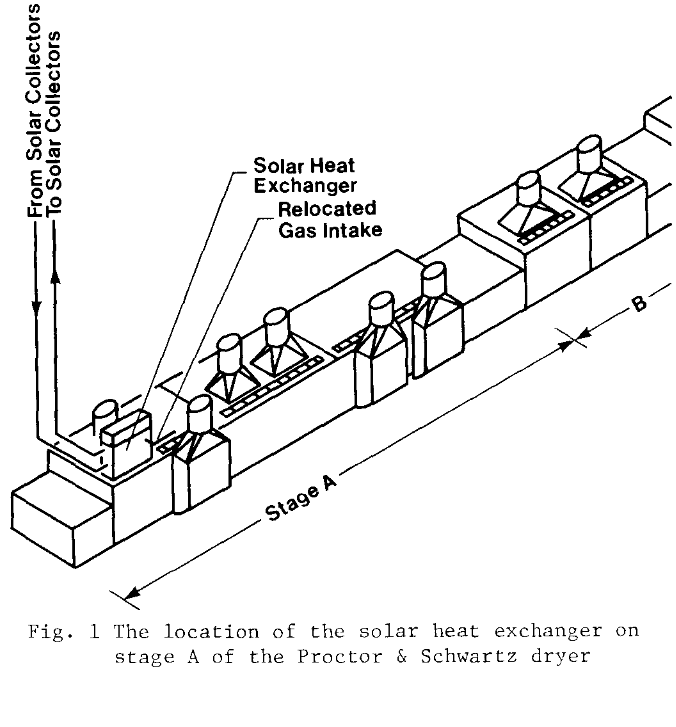

Fig. 1 The location of the solar heat exchanger on stage A of the Proctor & Schwartz dryer

SELECTION OF SOLAR COLLECTORS

Since each dryer draws in large quantities of ambient air and heats this to around 93° C (200° F) with direct firing from natural gas burners, a logical system choice seemed to be to preheat the air with simple solar air collectors located on the large roof area about 5 m above the dryer. Solar air collectors for this particular roof were ruled out because the roof is covered with many obstructions such as vents, skylights, and piping, and because this roof does not have the strength to support the addition of collectors. Warehouse K, which is a relatively new construction, has ample unobstructed roof area, and the roof is strong enough to support solar collectors. However, at its closest point, the roof is over 76 m (250 ft) from the dryer being considered. Losses from the pumping power requirements for moving large quantities of heated air from the roof to the dryers, especially over a somewhat tortuous ducting path, began to approach the energy gains expected from the solar collectors. It was for these reasons that solar air heaters were not selected to preheat the air entering the first stages of the dryer.

The decision to locate the solar collectors on warehouse K also dictated that the heat transfer medium be a fluid. A fluid, preferably water, could be pumped the distance to the dryer with reasonable pumping power without great losses in the heat energy collected. Tracking concentrating collectors were ruled out because the Gilroy plant has only a small staff of engineers, and it was thought that the continually moving collectors, over the lifetime of a system -- say 20 years, would require more attention and maintenance than could be expected to be added to the duties of the engineering staff. The decision was thus further narrowed to some type of flat plate collector.

The heat exchanger which was placed within the air duct entrance to the initial stage of the dryer, as shown in Fig. 1, was sized to match the acceptable air flow through the gas burners as they now operate. A heat exchanger of special design having only a small number of fins had to be used because onion dust and skins have a tendency to collect in fins closely spaced together. This clogging of the fins with onion debris would greatly reduce the efficiency of the heat exchanger. The dryers and the associated wiring, piping, and peripheral equipment are already in place, and this placed a practical limitation on the size of the heat exchanger. The collector field size of 553 m^2 (5950 ft^2) was dictated by the requirements of the heat exchanger.

Although a limited amount of drying of specialized products is done during the off-season, the bulk of the drying is accomplished in a 183-day period during late spring, summer, and early fall. This means that an expensive solar system is not being utilized for drying for almost half the year. The Gilroy plant has a boiler which is used year round for a source of supplemental heat and for cleaning the dryers. To make use of the solar system year round, as long as the heated water from the solar system is above 60° C (140° F) and not in demand from the dryer heat exchanger, it is diverted to the condensate tank of the boiler where it helps to preheat water eventually used by the boiler. The demands for heat energy by the dryer or by the condensate tank are so large that all of the energy produced by the solar system is consumed and there is no need for an expensive storage system.

The temperature requirements dictated by the heat exchanger and by the condensate tank which were in the range from 60° C to 93° C (140° F to 200° F) led to the decision to choose high performance flat plate collectors which use evacuated tubes as the collector. A number of flat plate collectors which were not the evacuated tube type were first considered. These were rejected largely because their efficiencies rapidly drop off when these collectors are used in the desired temperature range. Even when these collectors were operated at a marginal temperature near 60° C (140° F), their efficiencies were considerably less than the evacuated tube collectors. Fig. 2 compares the efficiencies of typical flat plate collectors and an evacuated tube collector, and it gives an indication of the range of temperatures in which they are to operate(2).

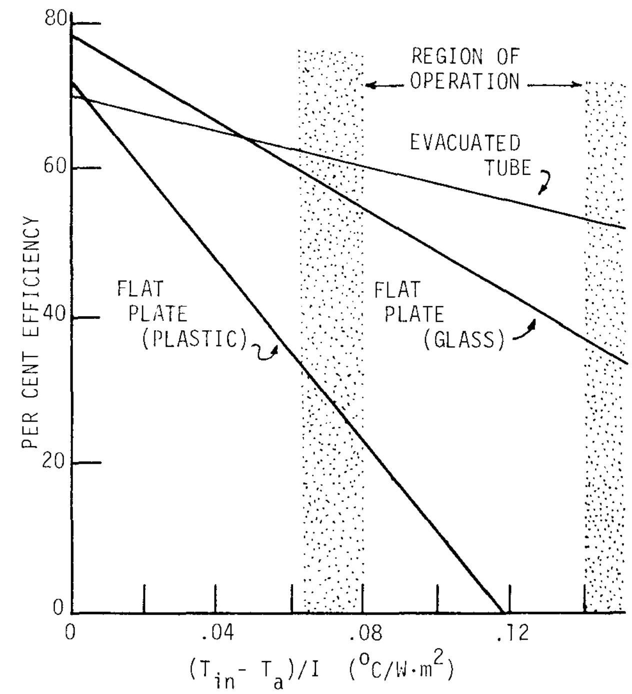

Fig. 2 Comparison of efficiencies of flat plate collectors and an evacuated tube collector

The cost per unit area of flat plate collectors is somewhat less than that of evacuated tube collectors. The greater efficiency of the evacuated collectors means that fewer of these collectors are required to deliver the same energy as a given area of flat plate collectors, and this tends to offset the cost per unit area. From DOE-sponsored projects on the use of solar energy in industrial processes, it has been found that costs for support structures and installation of collectors can run between 30% and 80% of the total cost of the collectors themselves. This means that a smaller collector field makes a reduction in cost of support structure and installation, reducing significantly the overall cost per unit of energy delivered.

Evacuated Tube Collectors

The high performance of this type of collector is achieved by a vacuum insulating jacket and by a non-imaging concentrator. As shown in Fig. 3, an outer glass cylinder serves as a window, and an inner cylinder with a selective coating is the absorber. The selective coating on the absorber tube is protected from the deteriorating effects of moisture and the constituents of ambient air by the evacuated space between the jacket and the absorber tube. Reverse loss of heat from the absorber tube by conduction and convection is quite small because the evacuated region insulates the tube. Losses by radiation are made small by the selective coating whose absorptivity-emissivity is wavelength selective.

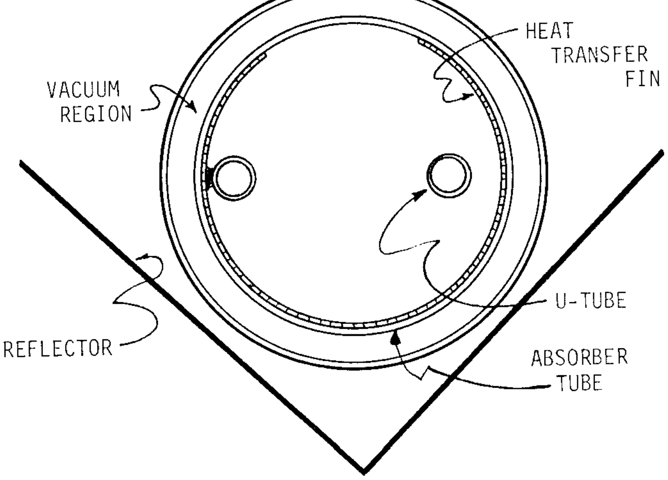

Fig. 3 Cross section of an evacuated tube collector

The solar radiation collected by the absorber is conducted through the inner glass cylinder through an air gap and into a metal fin which conforms to the inside diameter. Thermal energy is then removed by a fluid flowing through a U-tube flow passage. Individual tubes are grouped in a modular form with ten glass tubes mounted parallel to each other in the reflector assembly as shown in Fig. 4. A single module has an effective collecting area of 1.37m^2 (14.8 ft^2). The entire system will be using a total of 402 modules. Tubes are placed in a simple Vee-trough reflector which helps to increase the collection of diffuse as well as direct radiation. The weight per unit area for a module filled with water is 17 kgf/m^2 (3.6 lbs/ft^2). The U-shaped tubes are interconnected to form a serpentine structure of ten loops in series, and a connection at either end allows for convenient connection with a manifold. Water which enters from the manifold passed through each of the ten tubes before it exits the module. In case of a potential freeze situation or an emergency shutdown, the tubes can be drained to prevent damage from freezing or steam flashing. Stagnation temperatures of 370° C (700° F) can be tolerated without damage to the collector tube or the selective coating.

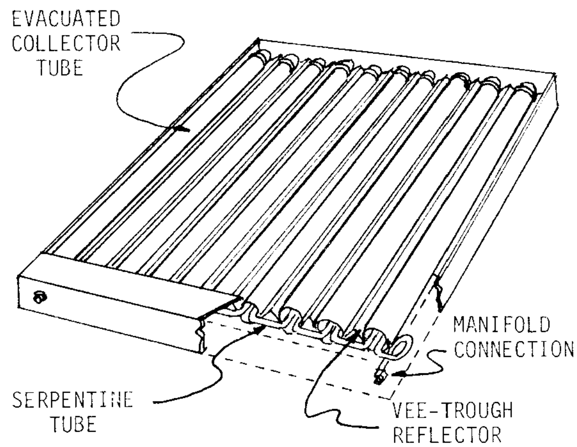

Fig. 4 A single module containing evacuated tube collectors

The data in Table 1 gives the averages for ambient day-time temperatures for the Gilroy area, the daily insolation on a horizontal surface, and the number of daylight hours. Because the drying season is in the summer, the inclination angle was set at 20° in order to collect the maximum radiation from the summer sun. The total energy collected by this system is expected to be on the order of 2.5 x 10^{12} J/yr (2.4 x 10^3 MBTU/yr). Piping systems losses during operation and piping heat losses, particuarly at night, will be about 9% of the total energy collected, and collector night losses will be on the order of 1.0% of the total energy collected.

Table 1

Insolation Conditions at Gilroy, California

Gilroy (ϕ = 37°), Inclination angle, s= 20°, T_{in} = 71° C (160°F)

Month	Average Day-Time Temperature		Insolation on a Horizontal Surface	Average Daylight
	°C	°F	(MJ/d. m^2)	(Hours)
Jan	11.7	53	8.17	9.75
Feb	12.8	55	11.7	10.7
Mar	14.4	58	17.8	11.8
Apr	15.6	60	22.0	13.0
May	21.1	70	25.1	14.0
Jun	23.3	74	27.2	14.5
Jul	23.9	75	26.0	14.3
Aug	23.9	75	23.5	13.4
Sep	23.9	75	19.6	12.3
Oct	18.9	66	14.6	11.1
Nov	13.9	57	10.1	10.0
Dec	12.2	54	7.15	9.48

OVERALL SYSTEM

The schematic diagram in Fig. 5 shows the solar system and the piping scheme which delivers energy to the heat exchanger in the dryer and to the boiler condensate tank[4]. The solar field is divided into four arrays, each of which can be isolated from the rest of the system. Provision is made for each array to be vented manually when the collectors are being filled with water or automatically when air collects in the system and needs to be removed. There is no need for a freeze protection mode for an evacuated tube collector in the Gilroy area; but as a safeguard, the pump will start circulation of water again if the temperature in the header were ever to drop below 3° C (38° F). This would draw warmer water into the collectors and prevent freezing in the collector tubes or the piping.

° Mode 3: Circulate, Preheat Air, and Preheat Boiler Feed -- Under some operating conditions, the overall system efficiency can be improved by withdrawing water from the condensate tank, absorbing solar energy in the field, preheating air in the first stage of the dryer, and supplying preheated boiler feedwater.

° Mode 4: Preheat Boiler Feedwater -- This mode is used for preheating boiler feedwater when the dryer is operating with gas heat only, or when the dryer is shut down in the off-season.

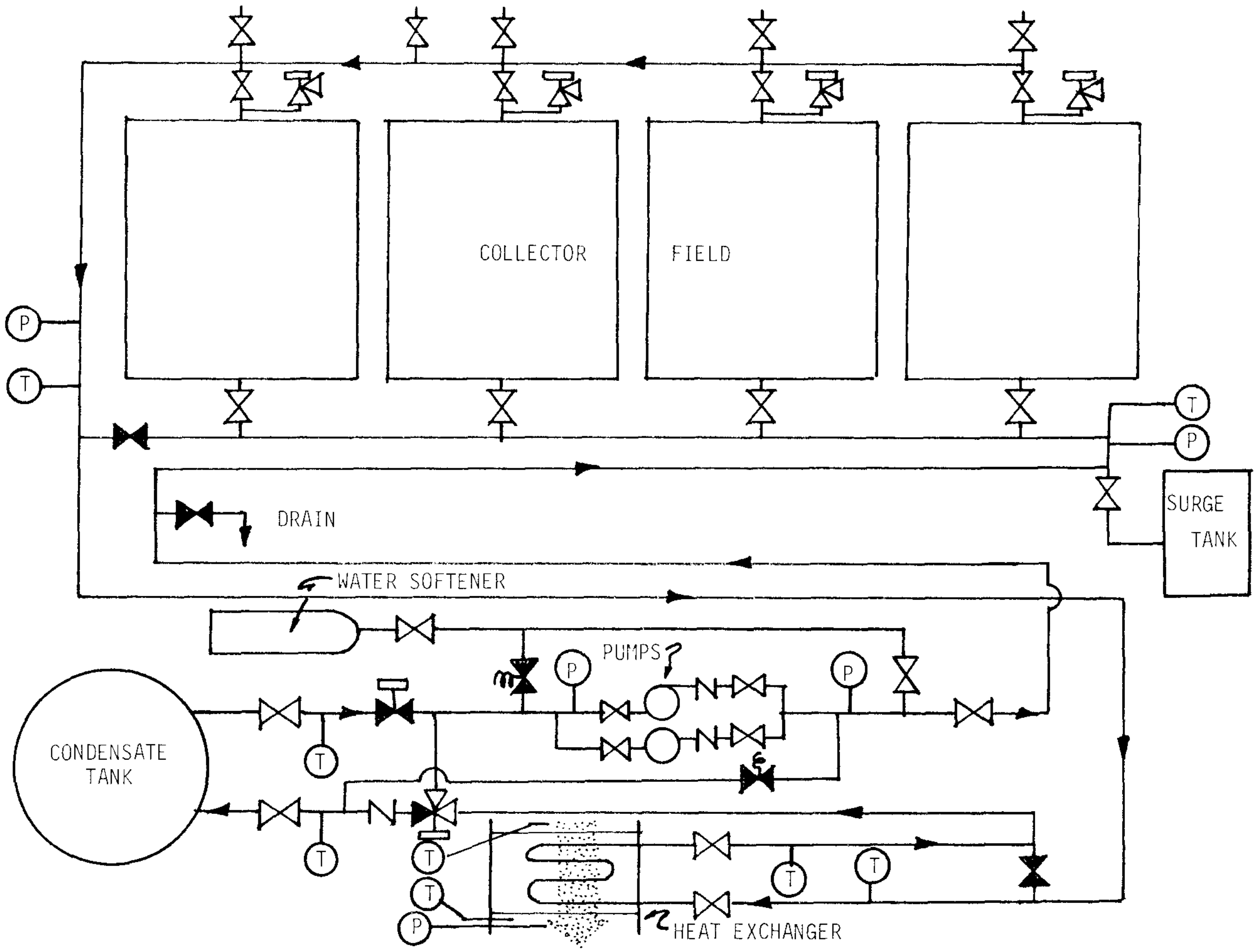

Fig. 5 Solar system and piping scheme

An Acurex Autodata Nine Acquisition and Control System (DACS), block diagramed in Fig. 6, will monitor and control the entire system. The four basic modes of the system operation are:

° Mode 1: Circulate and Bypass Load -- This mode is used for the system checkout and for freeze protection.

° Mode 2: Circulate and Preheat Air -- This is the normal operating mode. Circulation is initiated when insolation reaches a set level which has been entered into the DACS.

Manual push button control is provided so that any valve or pump can be operated in the opposite position to that called for by the automatic system if desired. When the manual control is released, the system reverts to the automatic mode of DACS. In addition to the control of the solar heating system, the DACS also monitors weather and temperature information. Twenty resistance thermometers are monitored; and they will measure the temperatures of the ambient air, water in the collector modules, the air entering and leaving the heat exchanger, the water in the headers, and the lines to the condensate tank. Direct and diffuse radiation on the tilted surface will be monitored every 30 seconds and then integrated on an hourly and daily basis. The flow rate of water through the collector will also be monitored. All of the data will be collected on a data cassette, and half-hourly information accumulated on this cassette will be dumped via teletype printer once a day.

4 DOE Contract EY-76-C-05-5119 (modification No. A005), June, 1978.

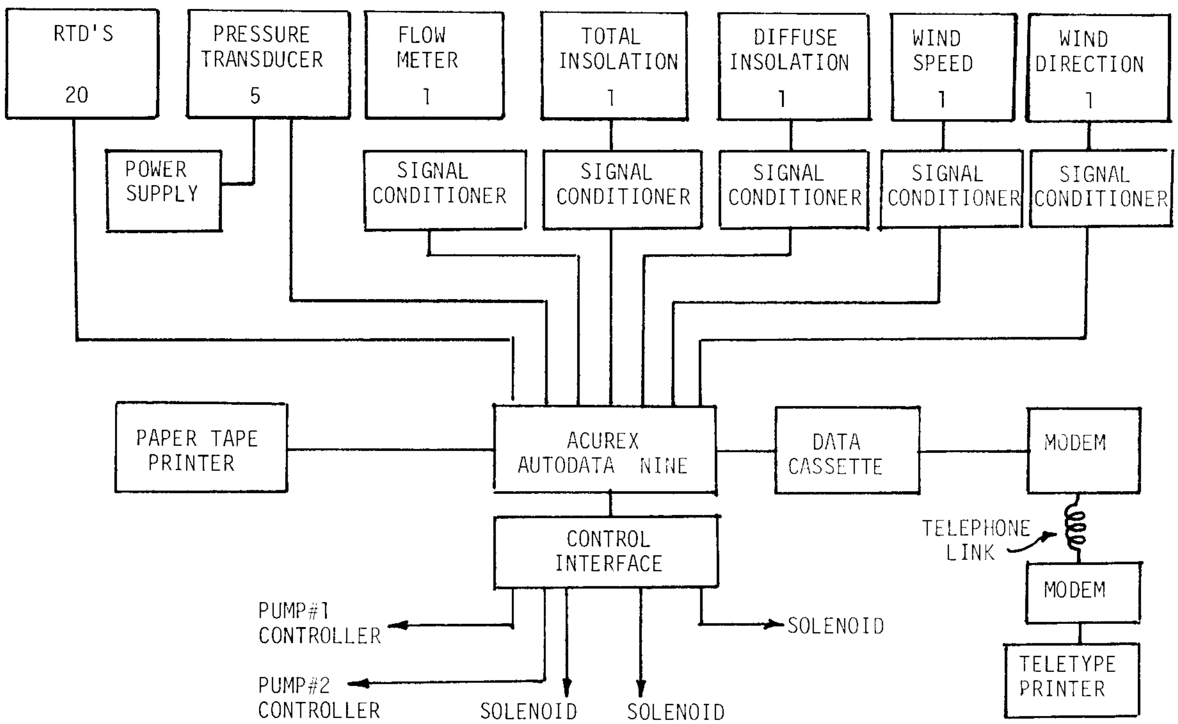

Fig. 6 Data acquisition and control system

A test station consisting of two side-by-side modules has been set up on the roof of warehouse K to see if dust, particularly onion dust, will have a significant effect on the efficiency of the evacuated tube collector and the reflector backing. One of the modules will be cleaned regularly and the other will not be cleaned at all during the test period. The main array of solar collectors will be placed on the roof after the 1978 drying season is over. This system will be checked out during the winter of 1978, and it will be ready to start its operation for the 1979 drying season.

REFERENCES

1 Chizek, G. J. and Genereux, D. G., Task 3, Report NSF Grant GI-42944.

2 Mattier, G. R. and Beekley, P. C., "Performance of an Evacuated Tubular Collector Using Non-imaging Reflectors", available from Owens-Illinois.

3 "Application of Solar Energy to Continuous Belt Dehydration, Final Report", Trident Engineering Associates, Inc., DOE Contract E-(40-1)-5119, November 21, 1977.