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DEVELOPMENT, TESTING, AND CERTIFICATION OF CALMAC MANUFACTURING CORPORATION SOLAR COLLECTOR AND SOLAR OPERATED PUMP--FINAL REPORT

By John C. Parker
Solar Heating and Cooling Projects Office
George C. Marshall Space Flight Center, Alabama
National Aeronautics and Space Administration

For the U. S. Department of Energy

U.S. Department of Energy

Solar Energy

DISCLAIMER

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16. ABSTRACT

This report presents a summary of the final results of Contract NAS8-32253 with the Calmac Manufacturing Corporation of Englewood, New Jersey, for the additional development work on their existing rubber tube solar collector and solar operated pump for use with solar heating and cooling systems. It discusses the intended use of the final report, describes the development hardware, lists deliverable end items, deals with problems encountered during fabrication and testing, and includes certification statements of performance.

This report shows that the products developed are marketable and suitable for public use, with limitations.

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TECHNICAL MEMORANDUM

DEVELOPMENT, TESTING, AND CERTIFICATION OF CLAMAC MFG. CORP. SOLAR COLLECTOR AND SOLAR OPERATED PUMP – FINAL REPORT

SUMMARY

This report is intended to provide product development information as an aid to the solar systems building industry in their effort to determine the products suitability for use in a specifically configured total solar heating and/or cooling system in residential and commercial dwellings.

This report will also serve as an aid to those who desire to remain abreast of the state-of-the-art of solar energy heating and cooling projects.

Solar Collector

The solar collector as developed under this contract had its beginning as a flexible nonmetallic roll-out device fabricated using, basically, synthetic materials. This product was called "ice mat," for building ice rinks. Calmac analyzed this ice-mat to determine if it basically could be used as a solar collector. In 1975, after making some material substitutions and appropriately configuring it, Calmac, on their own, made up several prototypes, tested them, and sold a few for installation in houses. In October 1976, Calmac entered into a contract with NASA/MSFC to further upgrade their product so that it could be classified as marketable. At contract completion (over an 18-month period), Calmac obtained a certificate by Engineers Testing Laboratories, Inc., stating that there was no divergence from the interim performance criteria, the construction drawings, or service manual that would appreciably affect the installation, operation, or efficiency of the collector [1].

Two deliverable collector end items resulted from this development contract: (1) one is a factory assembled nonmetallic flat plate collector featuring a black plastic molding around the perimeter and one easily removable fiberglass glazing cover, and (2) the other is a field assembled nonmetallic flat plate collector without the molding and one fiberglass glazing cover cemented to the sides of the collector assembly.

A total of 300 ft^2 of collectors were delivered: nine factory assembled units, 4 by 8 ft, and one field assembled unit, 4 by 8 ft (Figs. 1 and 2). These Calmac collectors are not considered classified as, or intended to be, "high performance" collectors; therefore, they are not recommended for applications where the operating temperatures will exceed 210°F.

Solar Operated Pump

The solar operated pump as developed under this contract had its beginning during 1952 to 1959. The pumps built during this period were for applications other than solar heating and cooling of buildings. These applications had low temperature operating requirements and could be solar powered with a flat plate collector. Under this contract Calmac used a Northrup concentrating collector to power the pump in their efforts to further upgrade the product so that it could be classified as marketable. Material substitutions and certain configuration changes were made in an effort to increase the pumps performance; no success was achieved in proving that the pump could be 50 percent efficient as predicted. Late in the program an efficiency of 18 percent was accepted. At contract completion (over an 18-month period), a certification was signed by an independent agency, George Miles, PE, New Jersey, V. P. Pilot Machine Designers, stating that it met all requirements and was evaluated as fit for public use [2].

Three pumps were delivered under this contract, together with a Northrup concentrating solar collector to power the pump (Figs. 3 and 4).

The use of the solar-powered pump for solar heating and cooling projects depends on the development of a reliable, reasonably priced concentrating collector, as well as further development and testing of the pump.

No marketing plans have been formulated. However, it has potential application for irrigation or stock watering purposes.

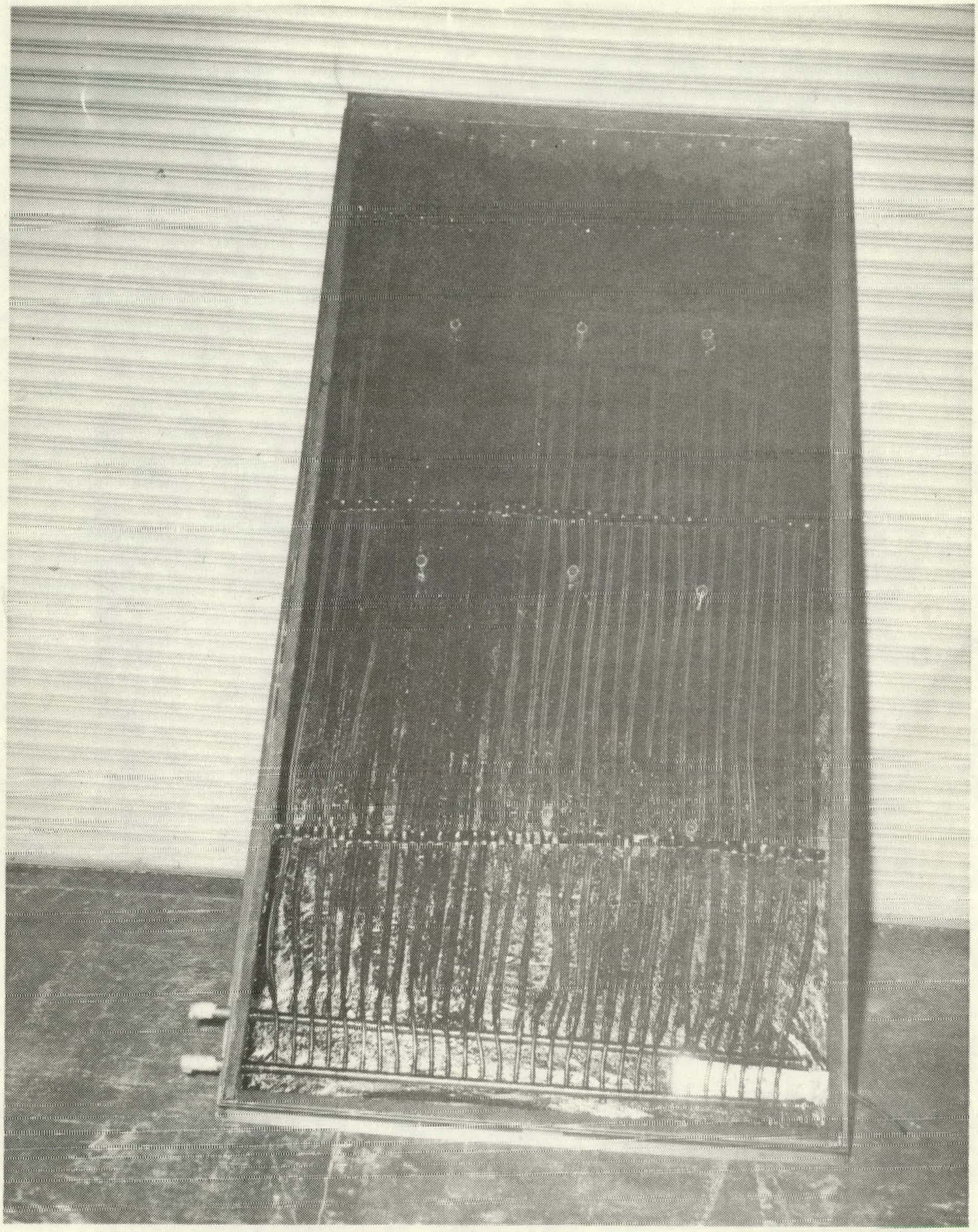


Figure 1. Factory assembled collector.

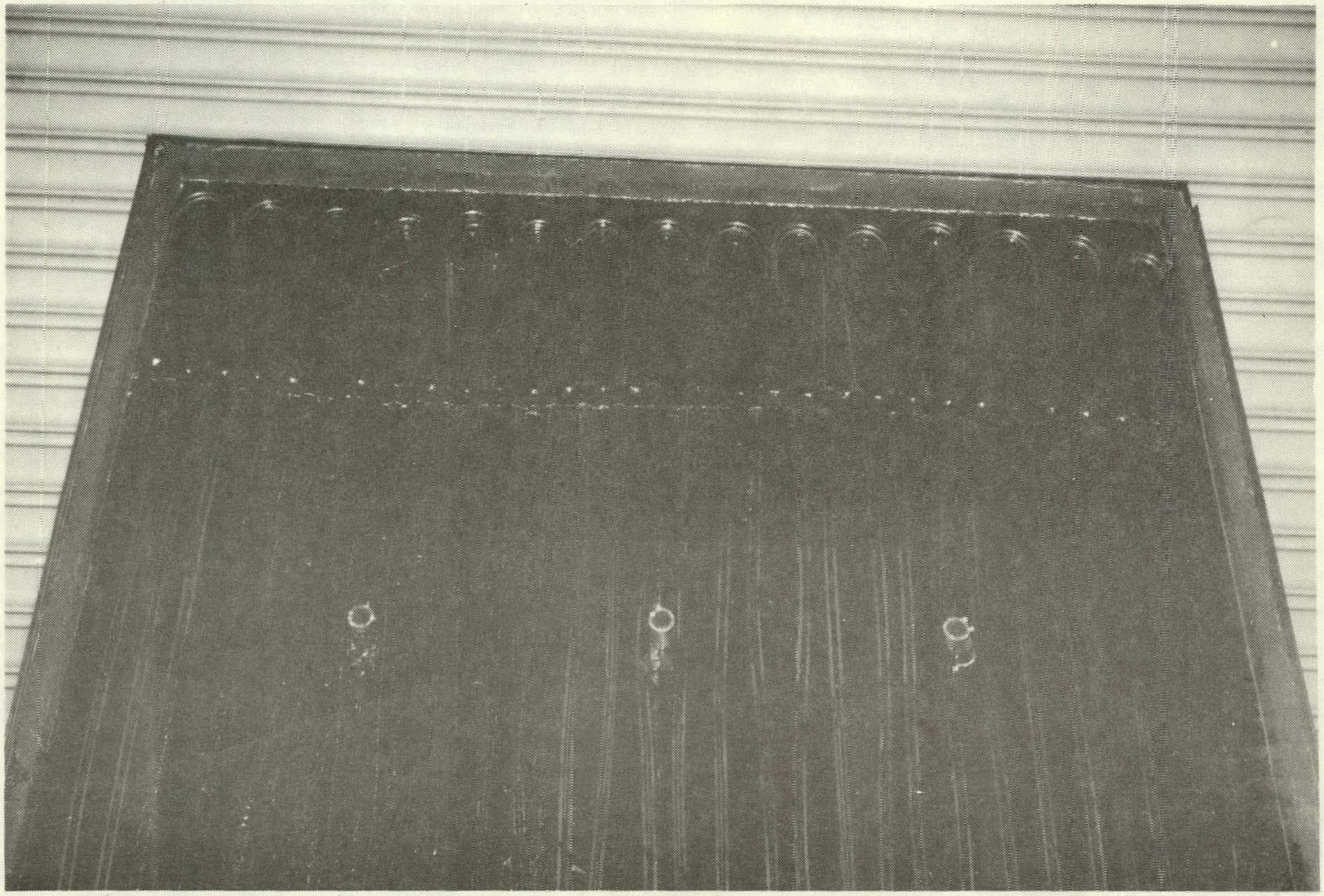


Figure 1. (Concluded).

Figure 2. Field assembled collector.

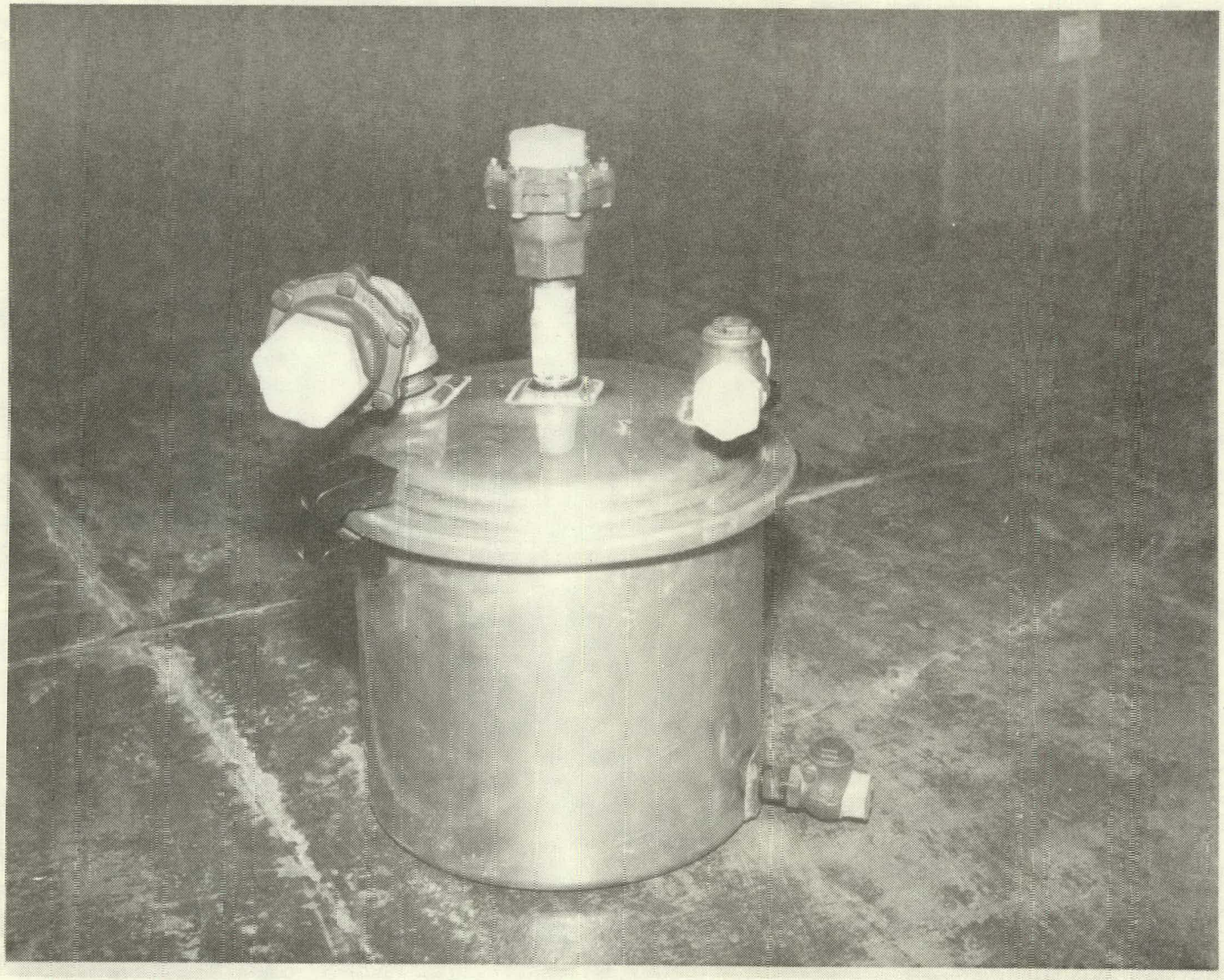


Figure 3. Solar pump.

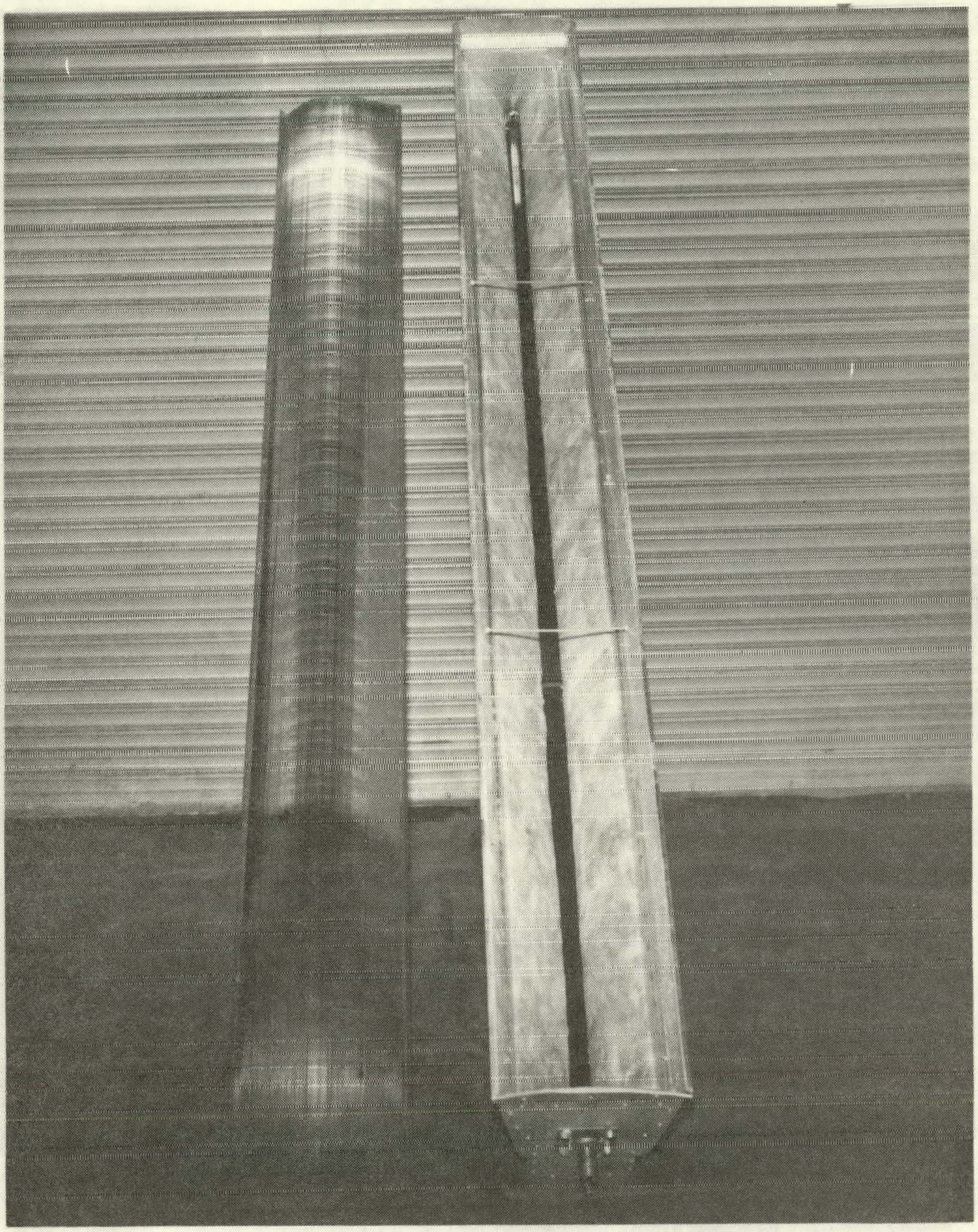


Figure 4. Concentrating collector.

INTRODUCTION

Program Background and Goals

Prior to dealing with the specific aspects of the Calmac solar collector and solar pump, a few background statements are pertinent. The problems of energy availability and increasing costs have led to a major national effort to develop alternate energy sources. One such source is the energy in solar radiation, which can be used for heating and cooling buildings, domestic hot water, and other applications. The National Energy Policy, as established in the Solar Heating and Cooling Demonstration Act of 1974 (PL93-409), is to provide for the demonstration of the practical use of solar heating technology within a 3-year period, and demonstration of the practical use of combined heating and cooling technology within a 5-year period. Responsibility for implementing the Demonstration Act was given to the Energy Research Development Administration (now the Department of Energy). The National Aeronautics and Space Administration (NASA), George C. Marshall Space Flight Center (MSFC) manages this work.

Purpose of this Product Development Contract

The purpose of this contract is to provide funding to the Calmac Manufacturing Corporation to do additional design, development, fabrication, and test work on their existing subsystems (solar collector and solar operated pump) so that each subsystem can be classified as a marketable product and fit for public use [6].

In the case of the collectors, the purpose was to determine if nonmetallic flat plate collectors made with mostly synthetic materials can meet the same performance criteria, specifications, and nationally recognized standards and codes that are applicable to metallic flat plate collectors, and be cost effective.

In the case of the solar operated pump, the purpose was to determine if the pump has any application for usage in solar systems designed to heat water or to heat and cool buildings in remote areas that do not have electrical power readily available.

Contract performance period was from October 15, 1976, through May 15, 1978.

DESCRIPTION

Project Development Requirements and Criteria

During the development of the collector and pump, the contractor was required to:

a) Meet the applicable parts of the interim performance criteria for solar heating and cooling systems.

b) Meet the subsystems performance specifications [7].

c) Provide test data/analysis to verify that hardware meets the subsystem performance specification.

d) Provide drawings and specifications in sufficient detail to define the configurations and to assure manufacturing repeatability.

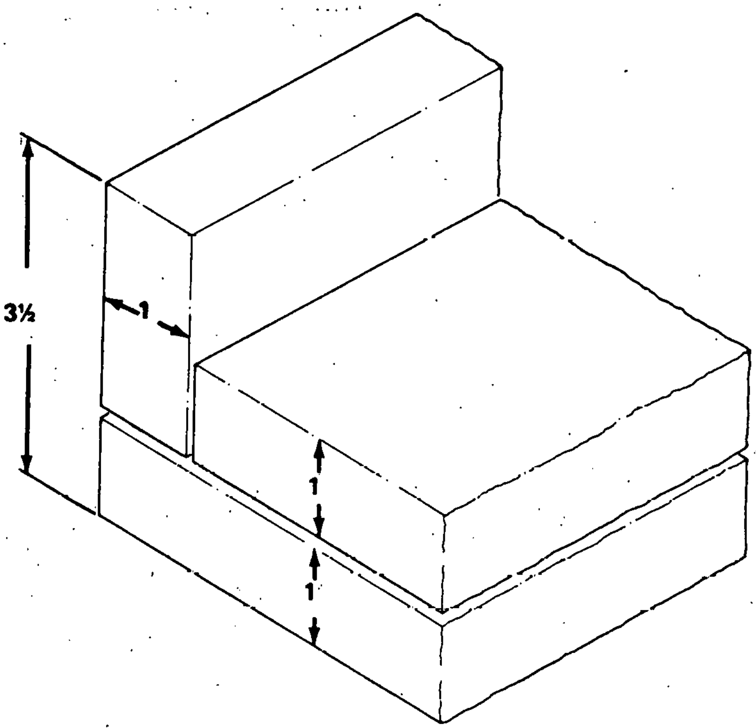
e) Provide installation, operation, and maintenance manuals [7].

f) Provide program execution plans, design review data, periodic status reports, and acceptance data packages.

g) Provide subsystem and/or component hardware certified by an independent test laboratory (such as Underwriters Laboratory and American Gas Association) to meet nationally recognized standards and codes (such as American Society of Heating, Refrigeration and Air Conditioning Engineers; American Society for Mechanical Engineers; American Standards Institute and American Refrigeration Institute).

Factory Assembled Nonmetallic Flat Plate Solar Collector Subsystem

The collector (trade name — Sunmat) consists of a flexible grid of 30 closely spaced elastometer twin tubes cemented to an insulation board base with a black high temperature urethane coating (Fig. 5). The tube material is



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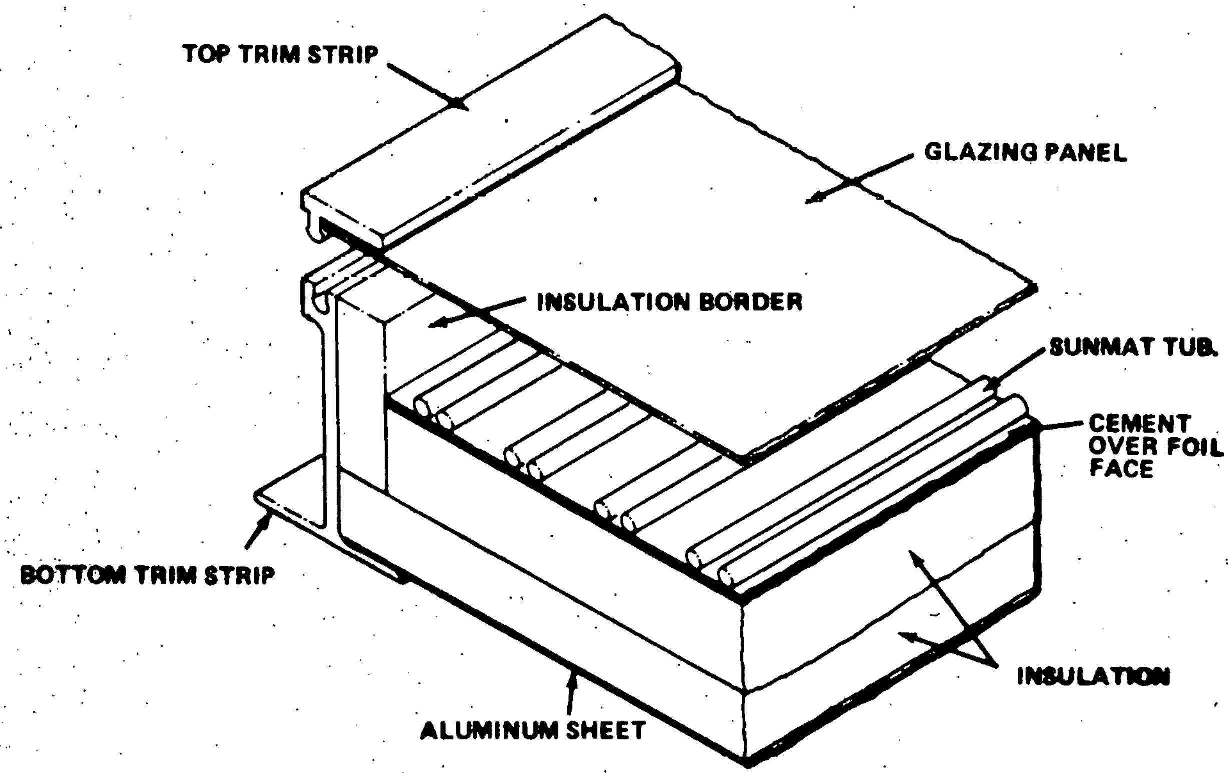


Figure 5. Cross section of factory assembled solar collector.

synthetic rubber (Ethylene Propylene Diene Monomer). The plastic grid substitutes for the metal absorber plate used in conventional metal collectors. The flat plate collector features a black plastic molding around the perimeter and a removable single glazing fiberglass panel. The collector comes in widths of 4 ft and lengths up to 25 ft.

Specifications for the factory assembled nonmetallic flat plate collector subsystem are as follows:

a) Cover Plate:

Fiberglass-reinforced polyester: 0.040 in.
Transmissivity: 88 percent at 0°, 78 percent at 45°
Wind load design: 100 mph

b) Absorber:

Surface: Black, high temperature urethane coating
Aluminum sheet: 0.002 in. thick
Tubing: 5/16 in. OD EPDM dual tubing

- Tube spacing 1-1/2 in. on center
- Manifold and outlet 3/4 in. OD type L copper
- Manifold-to-tubing connections 1/4 in. copper

c) Insulation:

High temperature (350°F) rigid fiberglass
Density: 4.0 lb/ft^3
2 in. on bottom, R = 9; 1 in. on sides, R = 4.5 at 70°F

d) Desiccant:

Silica gel in 3/4 by 10 in. wire mesh tube

e) Collector Frame:

0.125 in. thick Norylextrusion

f) Mounting Provisions:

1 in. flange around total perimeter
External plumbing connections 3/4 in. standard pipe thread

g) Fluid:

Capacity 0.03 gal/ft^3

h) Maximum Operating Temperature: 210°F

i) Maximum Allowable Temperature: 300°F

j) Design Life of Collector: 20 years

k) Fluid Pressures:

Maximum operating pressure: 20 psi
Tubing test pressure: 80 psi

l) Flow Rates:

0.018 gpm/ft^2 of mat
Minimum flow rate: 2.0 gpm

m) Nominal Pressure Drop:

0.16 psi/ft of length of mat

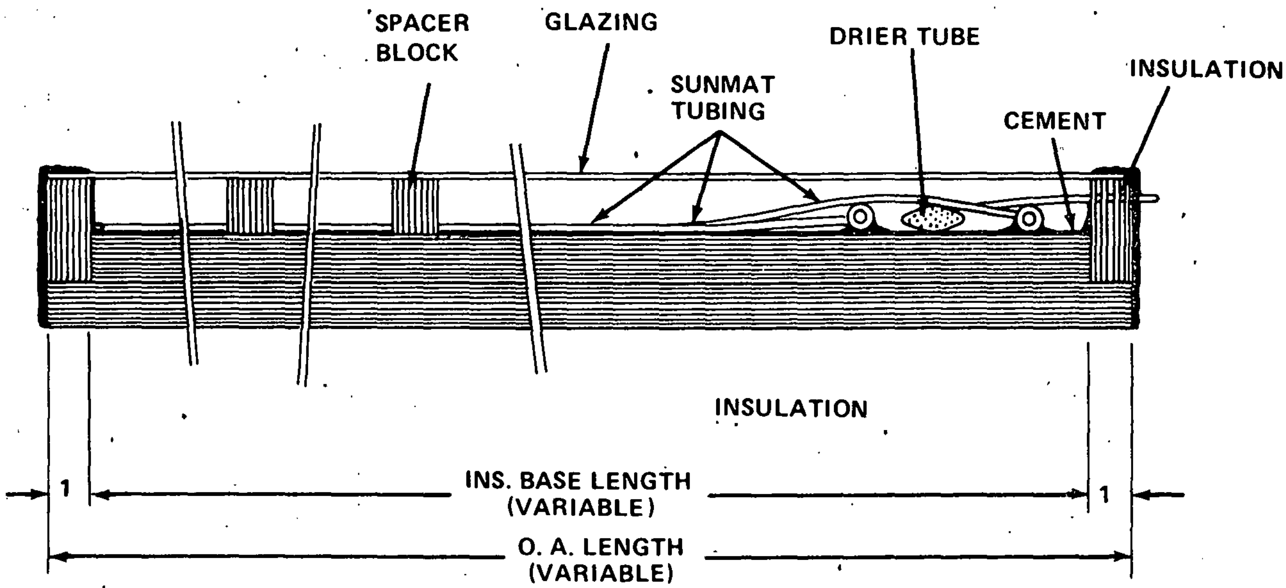
Field Assembled Nonmetallic Flat Plate Solar Collector Subsystem

The collector (Fig. 6) in this subsystem is similar to the factory assembled type except that it has no plastic molding around the perimeter and it has a cement sealed flexible reinforced single glazing plastic cover, in place of the removable panel type. The collector comes in widths of 4 ft and in lengths up to 50 ft.

Specifications for the field-assembled collector subsystems are as follows:

a) Physical Data:

Width: 4 ft
Length: Up to 50 ft
Depth: 3-1/2 in.
Weight (unfilled): 2.0 lb/ft^2
Coolant weight: 0.2 lb/ft^2



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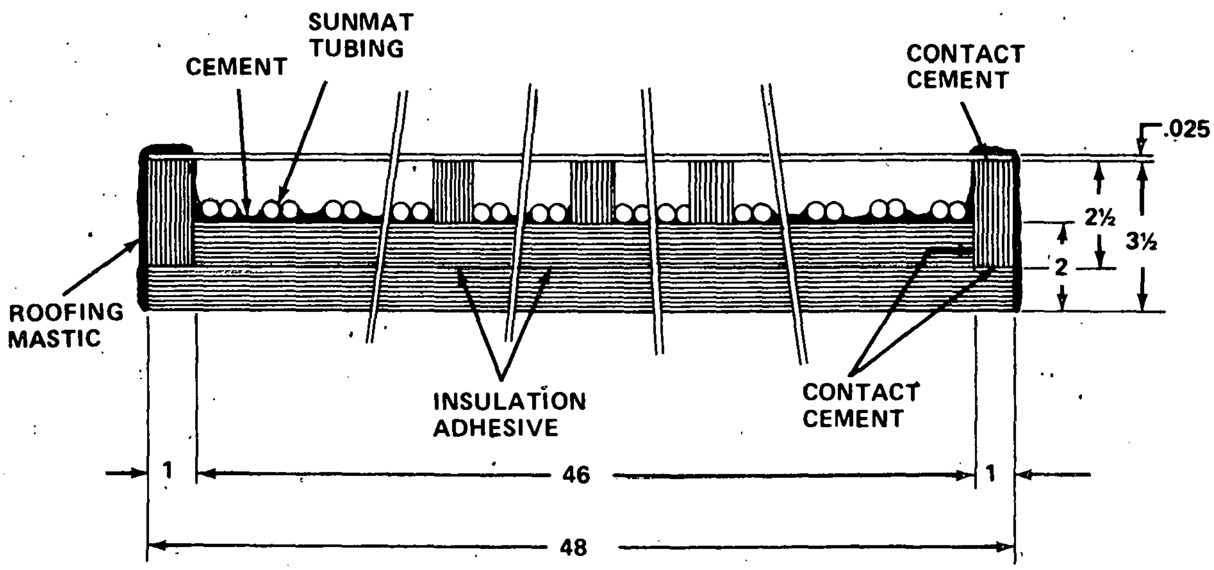

Figure 6. Cross section of field assembled solar collector.

b) Glazing:

0.025 in. gauge fiberglass-reinforced polyester. 88 percent solar transmittance at 0°, 78 percent at 45°. Kalwall SUN-LITE Premium II or equivalent.

c) Absorber:

5/16 in. OD, 3/16 in. ID EPDM dual tubing spaced 1-1/2 in. on center bonded to insulation board with CAL-ZORB urethane cement. One gallon covers 40 ft^2.

d) Headers:

3/4 by 42-1/2 in. type L copper pipe. External connections are 3/4 in. threaded pipe connections soldered to the pipe. Connections to the absorber tubing are 1/4 in. nipples soldered to the pipe every 1-3/8 in. Two headers per mat.

e) Desiccant:

Silica gel in aluminum wire mesh tube. One dryer required for every 200 ft^2 of collector or fraction thereof.

f) Insulation:

Fiberglass duct board, high temperature (350°F), 3 lb/ft^3 density, foil-faced, 1 in. thick. Owens-Corning Fiberglass 703 or equivalent.

g) Adhesives:

Contact cement used to bond cover panel and perimeter walls to insulation bed, 3M 1300 Rubber Adhesive or equivalent. One gallon for every 130 ft^2 of collector. Adhesive used to waterproof the collector, roofing mastic. Adhesive used to bond insulation together, Foster 85-15 Stic-Safe Adhesive.

h) Coolant:

Water or mixture of glycol and water, 0.03 gal/ft^3.

i) Flow Rates:

0.018 gpm/ft^2 of mat, minimum of 2.0 gpm.

j) Pressure Drop:

0.16 psi/ft of length of mat, water. 0.2 psi/ft of length of mat, 40 percent ethylene glycol at 100°F.

k) Maximum Operating Temperature: 210°F

l) Maximum Allowable Tubing Temperature: 300°F

m) Fluid Pressure:

Maximum operating pressure, 20 psi. Tubing burst pressure, 80 psi.

$F_R U_L$: 0.86

$F_R (T a)_n$: 0.67

n) Collector Efficiency:

The curve shown in Figure 7 was plotted from data obtained during testing by Desert Sunshine Exposure Tests Inc. using a collector furnished by Calmac Manufacturing Corporation.

The curve shown in Figure 8 was plotted from data obtained during testing by NASA/MSFC using the MSFC solar simulator and a collector selected at random [3] from the end items delivered to MSFC by Calmac. The similarity of these curves demonstrates the consistency of the product performance resulting from effective manufacturing repeatability.

Solar Operated Pump

The pump (trade name — Thermo-Ten) is a heat operated pump designed to be powered by steam from concentrating solar collectors (Figs. 9 and 10). This type of pump when compared to mechanical pumps are characterized by

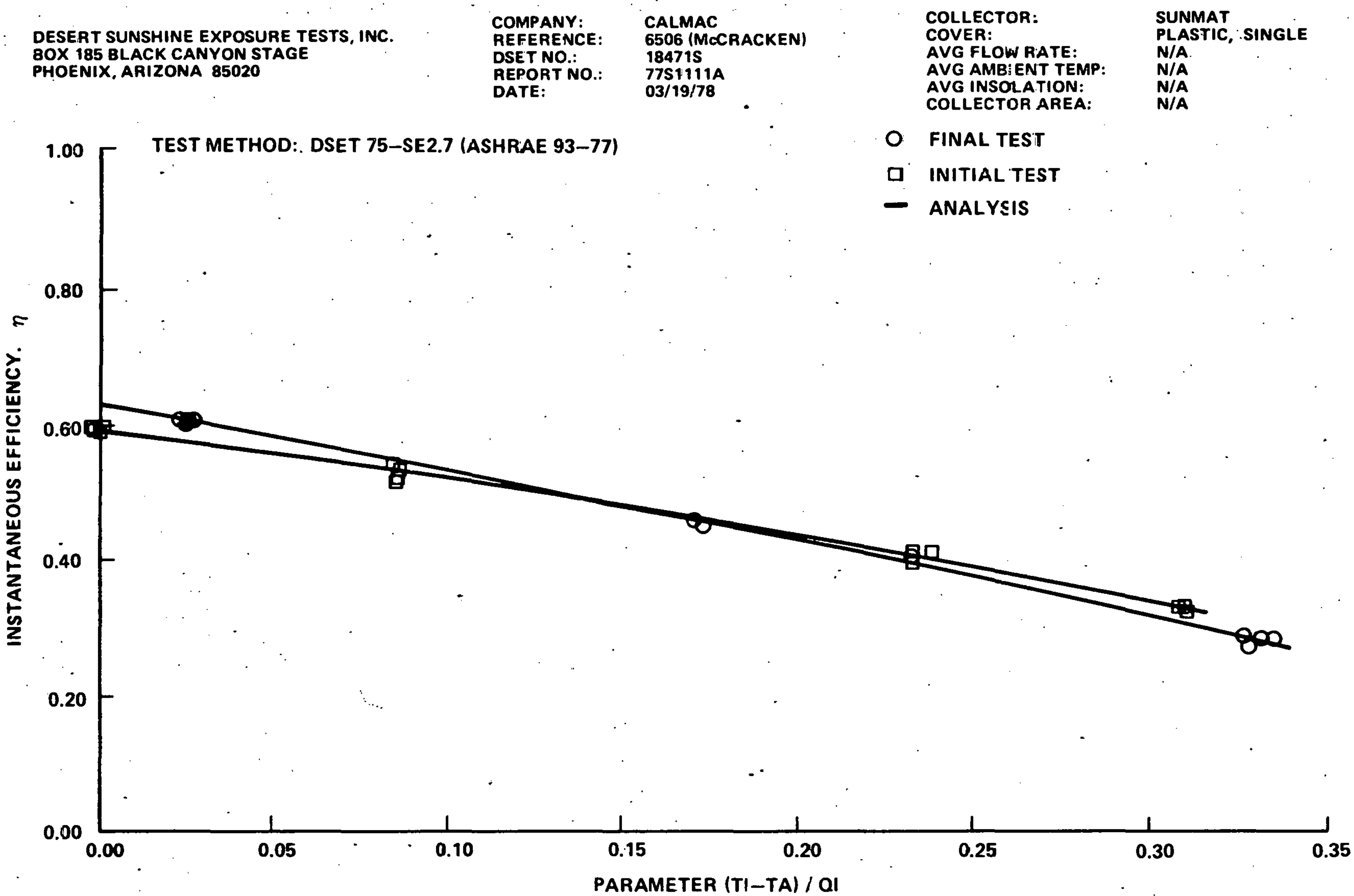

Figure 7. Instantaneous efficiency plot.

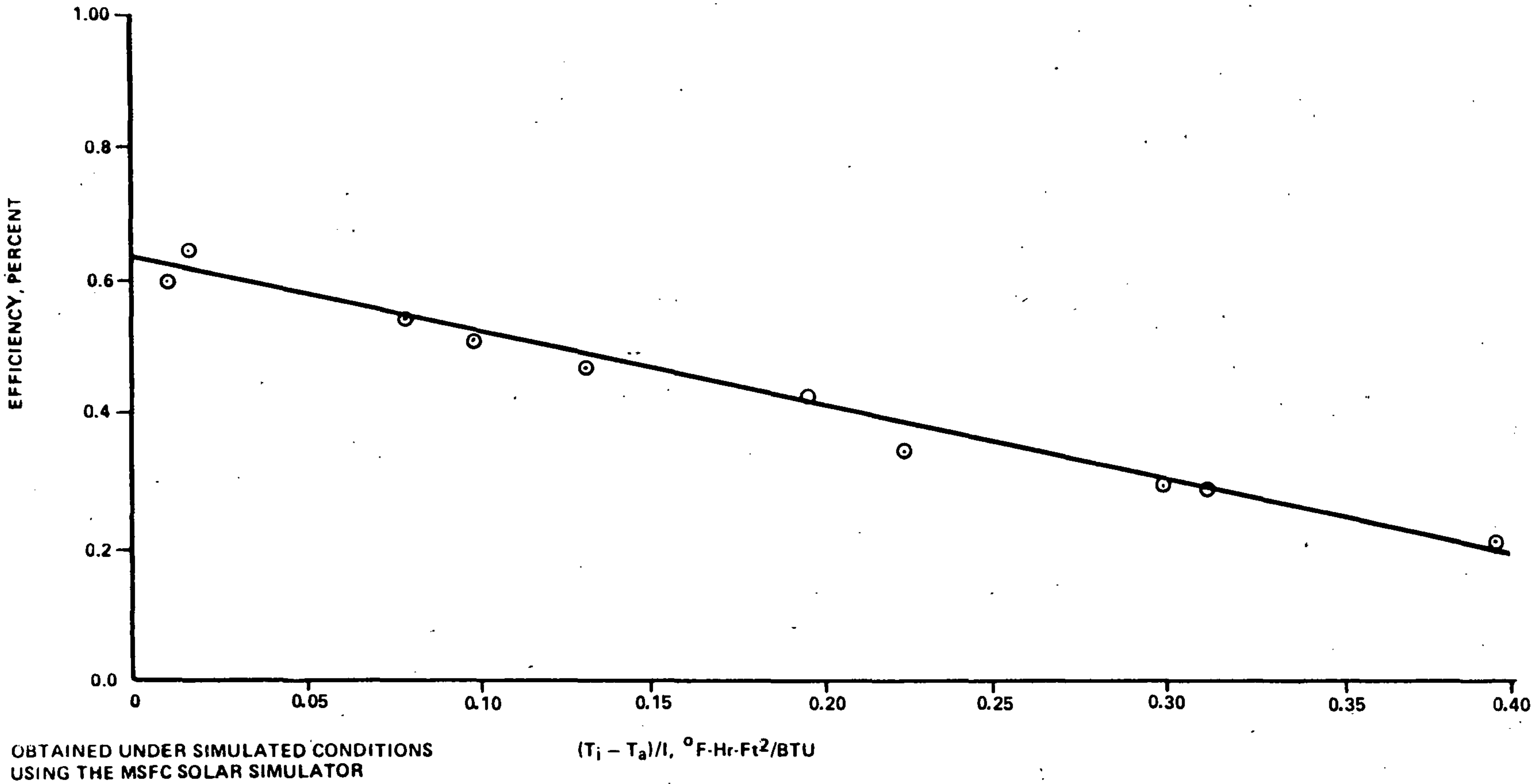

Figure 8. Thermal efficiency of Calmac liquid collector [3].

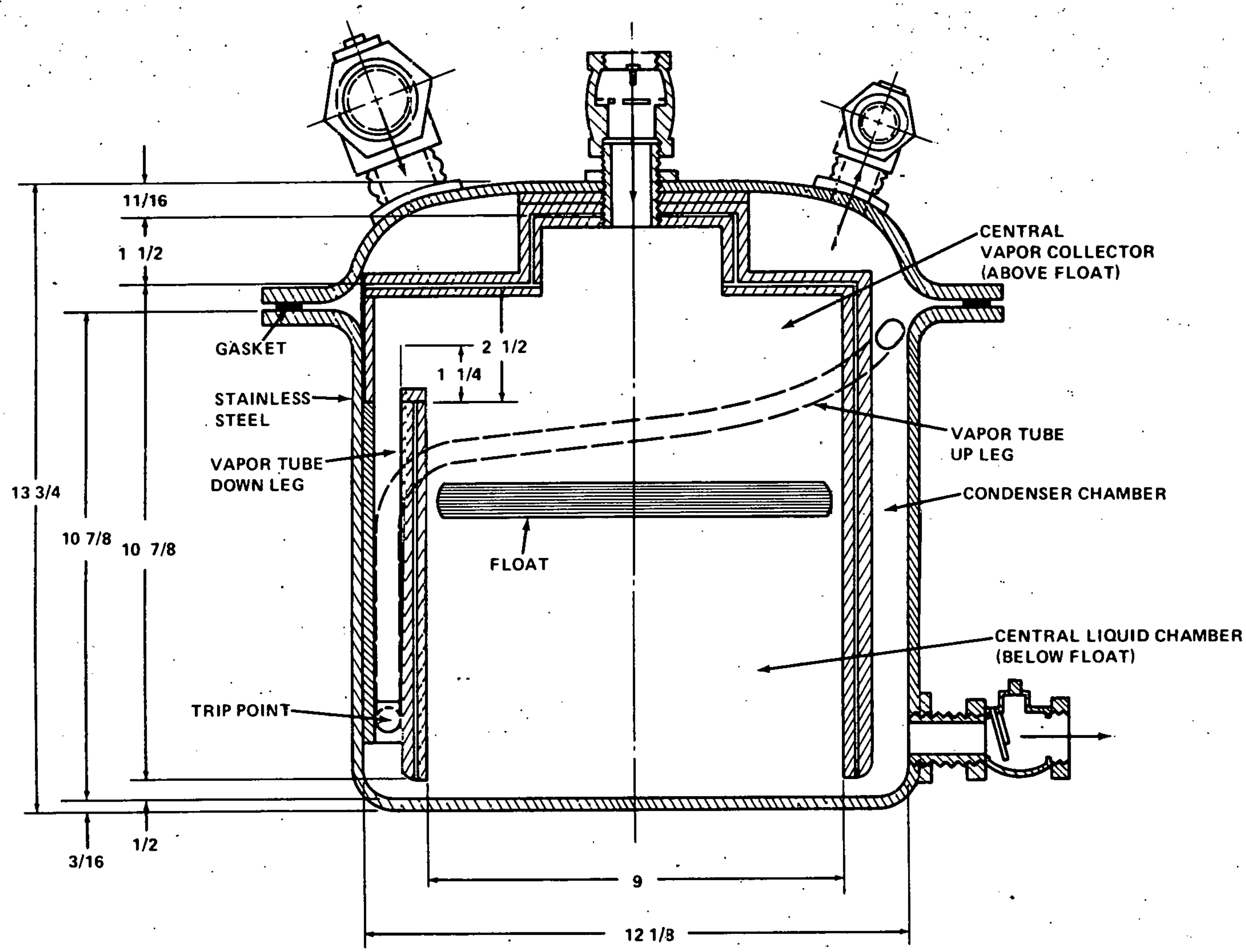

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Figure 9. Solar operated pump.

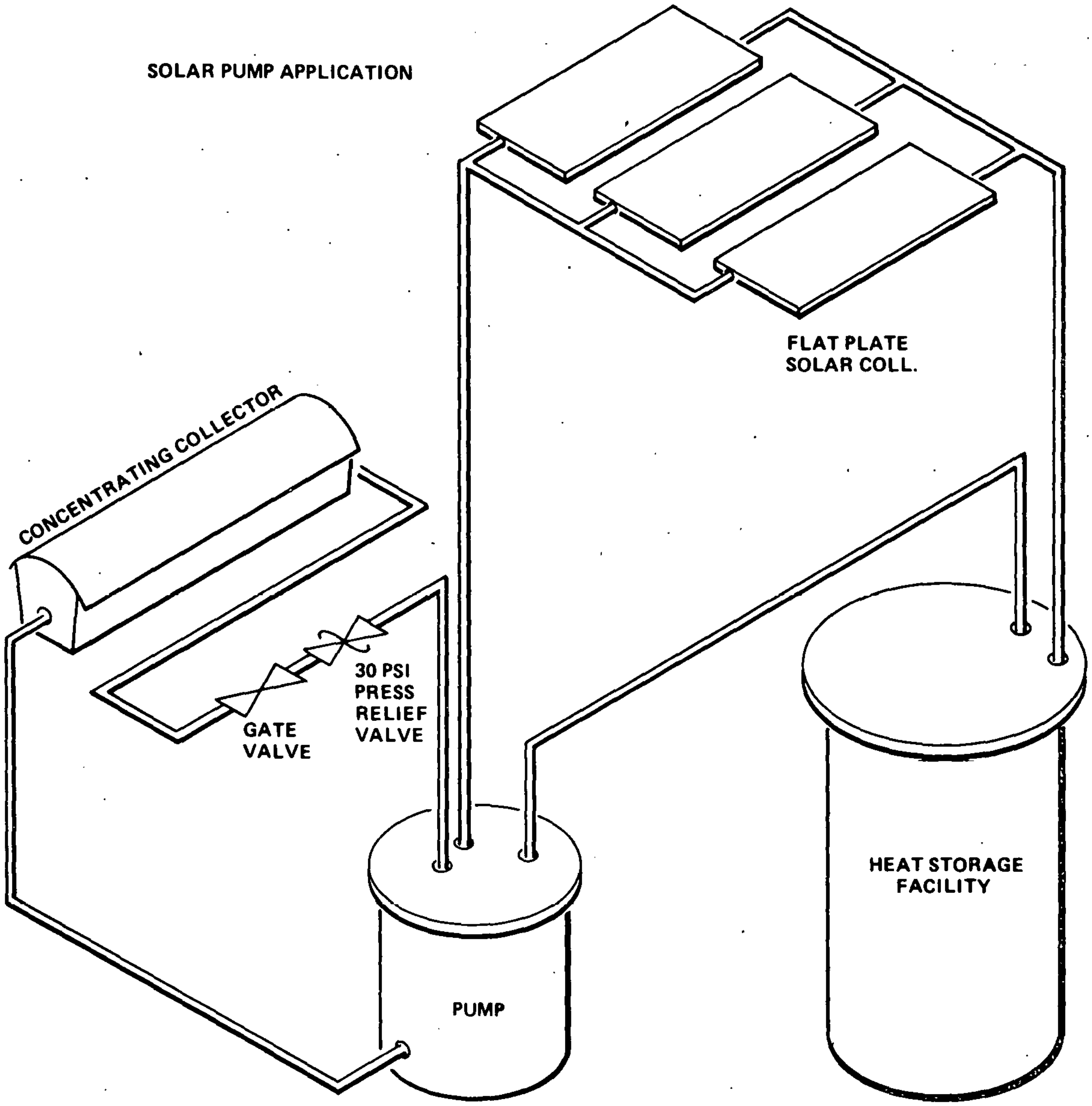

Figure 10. Solar pump application.

relatively low efficiencies and, therefore, are not necessarily intended for universal application, but lend themselves to unique rather than commonplace pumping problems. The pump as it would be used in solar heating and cooling systems can be classified as a unique application. Operation is similar to a coffee percolator, with some modifications through the incorporation of check valves. The fluid used to operate the pump, in this case, is the same fluid that the system is designed to pump. This feature minimizes, to some extent, the importance to be placed on thermal efficiency because the heat lost by the pump in its operation helps in raising the temperature of the solar system's heat transfer fluid.

Specifications for the solar operated pump are as follows:

Maximum flow: 10 gpm
Maximum discharge pressure: 50 ft of H_2O
Maximum suction pressure: 5 ft
Maximum fluid temperature: 200°F
Pump thermal efficiency: 9 percent to 25 percent
Maximum mechanical efficiency: 1.1 percent

PROBLEMS ENCOUNTERED AND THEIR SOLUTIONS [5]

Nonmetallic Flat Plate Solar Collectors

Early in the program, the collector design concept of a roll-out, field assembled collector was expanded to include a factory assembled collector to reduce, to a minimum, costly on-site assembly and installation work. This led to the need for a low cost frame assembly to enclose the collector panel. The configuration of this frame (extruded) had to be influenced by the number of glazing panels. So at this time a decision was made to change from double glazing to single glazing. (Double glazing should be a requirement only in very cold climates.) This resulted with an esthetically pleasing collector configuration which is highly desirable from a marketing standpoint for residential application. This configuration also provides easy access to collectors for maintenance.

Calculated collector efficiencies proved to be too optimistic. Tests were conducted at the Calmac facilities and at Desert Sunshine Exposure Tests Inc., and actual efficiencies "plotted out" below the calculated values. A specification change was authorized (Fig. 11). This curve (from tests) is comparable to other flat plate collectors featuring a black nonselective absortive coating.

The collector was not expected to get up to 300°F during stagnation tests. These unexpected high temperatures led to a redesign of header nipples and U bends, the selection of Stimson clamps on fluid carrying tubes, and changes in adhesive materials to insure against leaks in the fluid transport system. Also, adhesive materials originally selected fell short of complying with the vendor's own specifications; however, "Polyshim" and "Stic-safe" adhesives, the final selection, did the job [1].

The problem of outgassing of the collector insulation due to these excessive temperatures during 30-day stagnation tests led to the plan to outgas the insulation in an oven at 350°F at the factory prior to completing fabrication [1].

Other Collector Product Improvements

Metal angles and gusset plates incorporated into the plastic collector frame improved the structural integrity of the collector subsystem.

The factory assembled collector has incorporated into it a 0.002 in. thick aluminum sheet cemented over the entire bottom surface of the collector. This makes it water proof and eliminates the need to seal around each collector as it is placed into position on the roof.

Solar-Operated Pump

From the very beginning of the development program, we had experienced difficulty meeting the 50 percent efficiency called for in the basic specification. This was attributed to excessive heat losses through the cylinder wall. After trying a variety of different types of cylinder liners and sealants that were thought to have good insulation and "water run-off" characteristics, an inner cylinder cork liner with a silicone water sealant was used. This selection was a tradeoff between efficiency and pump capacity. Late in the program, a revision to the basic performance specification (SHC-3050) was approved changing the efficiency to 18 percent [4] because a material could not be found to adequately insulate the inner cylinder surface of the pump. A thicker insulation of the type decided upon would improve the efficiency but would reduce the volume of fluid that could be pumped through each stroke, which would reduce the capacity of the pump.

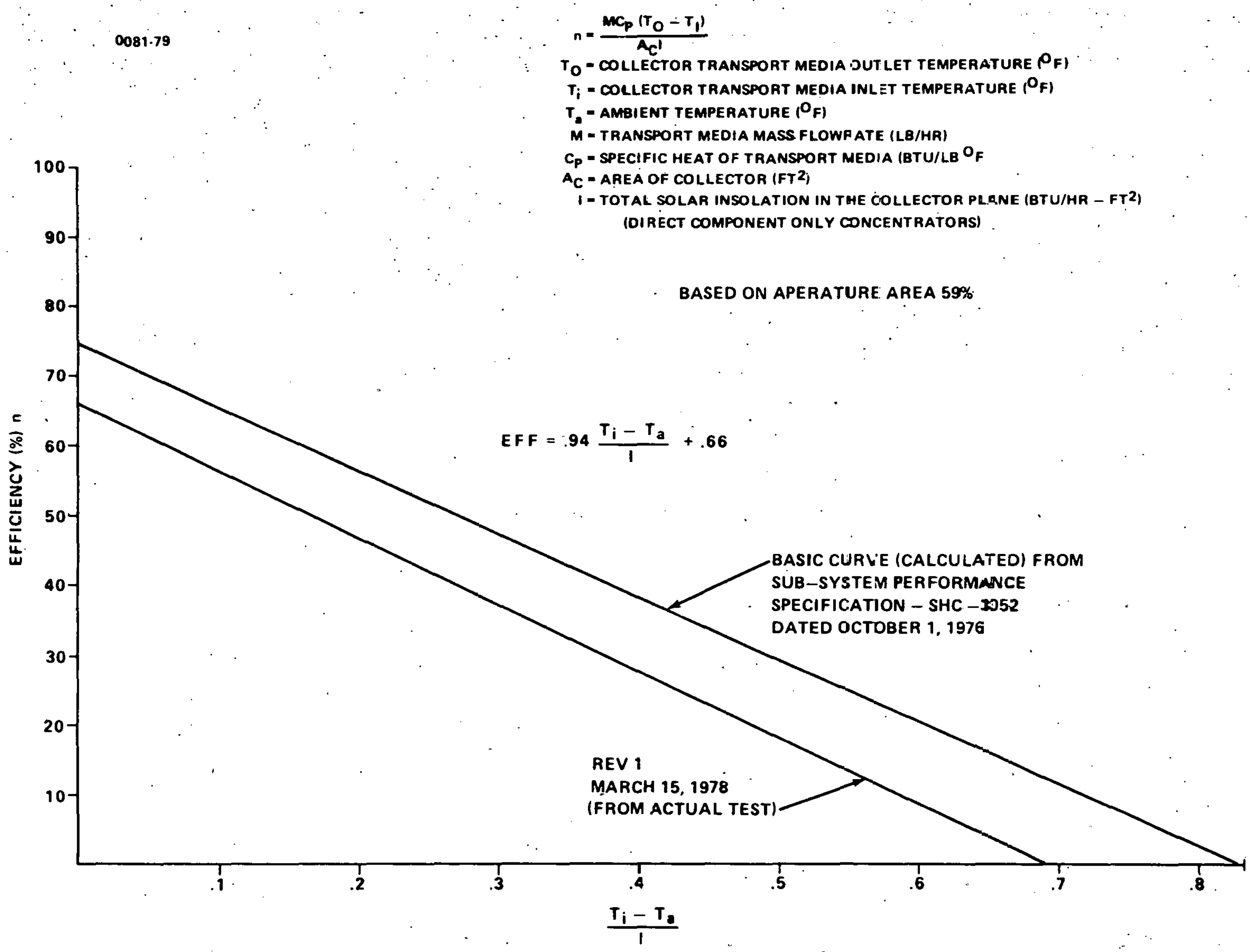

Figure 11. Efficiency as a function of operating conditions.

Other Pump Product Improvements

A change in the valve at the steam inlet improved the cycling of the pump and its performance on the suction stroke. The material of the outer cylinder of the vapor collector chamber was changed from aluminum alloy to stainless steel (the chamber must be able to withstand water and steam without deterioration). The pump installation, operations, and maintenance manual was revised to recommend that the pump not be installed in a living area; steam condensation during the suction part of the cycle is audible.

CONCLUSIONS AND RECOMMENDATIONS

Solar Collectors

Fabrication of flat plate collectors using nonmetallic synthetic materials is practical, cost effective, lightweight, and can meet the same performance criteria, specifications, and nationally recognized standards and codes that are applicable to metal flat plate collectors, with certain temperature and pressure limitations. The Calmac nonmetallic flat plate collectors are not recommended for applications where the operating temperatures will exceed 210°F and operating pressures exceed 20 psi. (A 400-hr flow test at 225°F and 40 psi resulted in gradual stretching and thinning of the elastometer rubber tubes, which is the carrier for the heat transfer fluid.)

The tubing configuration does not lend itself to a simple drain down operation. (Air pressure is required to completely remove fluid from the collector tubes). Therefore, ethylene glycol is recommended as the heat transfer fluid when the collector system is installed in climates experiencing freezing temperatures. In climates without freezing temperatures, it is not recommended that potable water be also the heat transfer fluid; continued efforts to verify that the EPDM rubber tubing used in the collector is suitable for use in potable water systems cannot be supported by available engineering data. Also, getting the tubing "taste free" was not successful.

Solar Operated Pump

Most of the product development effort devoted to the pump was in attempting to increase the pump efficiency. No work was done setting up a "breadboard" solar heating system consisting of the pump, a concentrating collector to power it, flat plate collectors, and storage tanks (Fig. 10) to permit an evaluation of the pumps effectiveness as part of a total system.

The pump must have a concentrating collector that will generate steam to power it if it is to have application in solar heating and cooling; much work remains to be done in developing a reliable, reasonably priced collector of this type.

Much work remains to be done to increase the pumps efficiency; the best efficiency that was attainable under this contract was 18 percent (50 percent was the initial goal). Until these considerations are properly addressed and results obtained and evaluated, the pump is an unlikely candidate for use in solar systems designed and built to heat and cool buildings. However, it has potential usage for irrigation or stock water purposes in remote locations where electricity is not readily available.

GENERAL

The referenced documents indicated by [ ] throughout the text are extensions of this final report and are recommended reading to provide a more detailed understanding of each hardware item developed under this contract. These documents may be obtained through the Department of Energy, Technical Information Center, Post Office Box 62, Oak Ridge, Tennessee 37830, or purchased from National Technical Information Service, Springfield, Virginia, 22151.

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APPROVAL

DEVELOPMENT, TESTING, AND CERTIFICATION OF CALMAC MFG. CORP. SOLAR COLLECTOR AND SOLAR OPERATED PUMP – FINAL REPORT

By John C. Parker

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

WILLIAM A. BROOKSBANK, JR.
Manager, Solar Heating and Cooling
Project Office

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