SERI/TP-253-2106
UC Category: 62e
DE84000015

Advanced Concentrator Research: Two Examples

L. M. Murphy

October 1983

Presented at the
Solar Thermal Workshop
Atlanta, Georgia
7-8 September 1983

Prepared under Task No. 1384.30
WPA No. 416

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

Prepared for the
U.S. Department of Energy
Contract No. DE-AC02-83CH10093

ADVANCED CONCENTRATOR RESEARCH: TWO EXAMPLES

by

L. M. Murphy, Ph.D.
Group Manager
Thermal Systems and Engineering Branch

Solar Energy Research Institute
Golden, Colorado 80401

INTRODUCTION

This paper briefly describes the major research efforts and findings at the Solar Energy Research Institute (SERI) on two innovative, potentially low-cost, concentrator concepts. The first concept discussed is the stretched-membrane heliostat, and the second is the polymer-enclosed parabolic dish.

STRETCHED-MEMBRANE HELIOSTAT

The need for heliostats with dramatically improved costs and performance was established by the value-based cost goal analysis developed by a joint industry/ Department of Energy cost-goal committee in 1981 [1]. The stretched-membrane concept can potentially meet a significant portion of that need. In this concept a reflector film—which can be metal, a polymer, or a composite—is stretched on a hollow torroidal frame that offers a structurally efficient and optically accurate surface (see Figure 1). This design, although intended primarily to improve heliostat concentrator performance and lower costs, may well offer the same opportunities for improvements in photovoltaic and daylighting applications as well.

To date, SERI's effort, detailed in Murphy [2], has focused on concept configuration, development, cost and performance analysis, and scale-model testing. Technical issues investigated include fabrication and attachment approaches, focusing and optical requirements, and the structural behavior of membranes and support structures. This last issue includes analysis of linear and nonlinear deformation, buckling of the support frame, thermal mismatch considerations, wind spillage effects, and the optimal strength and sizing of the membrane's support structure.

We costed several stretched-membrane concepts. We also designed and fabricated a number of bench-scale and field-test scale hardware elements, including two prototype concentrators 2 m in diameter and a potentially low-cost two-axis tracking support base; seven stretched-membrane reflective modules of various designs 1 m in diameter, which were tested for optical accuracy using a SERI-designed laser ray trace instrument test bed; and a reflector 3 m in diameter based on a commercial trampoline as an initial prototype. Further, we also tested a number of mechanisms for attaching membranes to support structures that are appropriate to either low or high production levels and evaluated seven candidate metallized polymers as potential reflective surfaces for stretched-membrane and other innovative concentrators.

The major advantages emerging from the research include the following: the reflector, support frame, and support structures can be made extremely lightweight and inexpensively because this concentrator makes the most effective use of material with high average stress levels in the reflector and suppport frame. Also, the simplicity of the design, which results in many fewer parts, should help reduce costs. We anticipate a 75% weight reduction of the reflector and support structure (down to the drive attachment) compared with the second-generation glass and metal heliostat concentrator. We also expect a better than 50% cost reduction for the reflector assembly and support structure compared with corresponding elements of the second-generation concentrator. Finally, we envision optical accuracies and annual energy delivery potential close to those attainable with current glass and metal heliostats. To get this high optical performance requires focusing, which can be accomplished in one of two ways [1], and a high quality polymer reflective surface.

Much development work still remains to verify and realize the full potential of the stretched-membrane concentrator. Remaining research is in three areas: systems performance and cost, materials, and mechanical and structural development.

Detailed costing and production analyses as well as a comparison of the annual cost of delivered energy with second-generation heliostats are needed. Optical surface accuracy analyses for membranes in real environments, correlated with and confirmed by experiments, should be used to support these system performance studies. We also need an impact assessment of seams, nonuniform and backside pressure loading, and ring imperfections as well as optimization studies that include the effects of weight reduction limitations, size constraints, and the applicability of scaling relationships.

Materials issues include determining the availability of durable, highly reflective polymer films for use with metallic structural membranes. We need more understanding on bonding or welding membranes (to the main structural frame and in forming wide sheets from multiple narrow sheets) in large-scale production environments. Testing and industry involvement are warranted at an early stage. Long-term materials issues include possible cost reductions through the development of polymer mirror laminates and polymer composite structural elements (i.e., the frame).

The most important issues on mechanical and structural research and development include refining the definitions of practical limits for further weight reductions (including the establishment of more precise buckling criteria for both local and gross stability as a function of heliostat size and design tension) and determining ways to enhance the buckling resistance of thin, tubular structures. In particular, we need to investigate the in-plane stability question, relating to the membrane tensioning and support frame, and verify the applicability of structural-stability scaling relationships by testing increasingly larger hardware elements. Furthermore, snap-through "oil canning" of laminated, curved membrane reflectors and aerodynamic load-reduction schemes for the reflector assembly should be studied.

POLYMER-ENCLOSED DISH CONCEPT

There is a need for small modular process heat systems that deliver energy in the 540° C (1000°F) temperature range, and the low-cost dish technology was suggested as a possibility to meet this need. One concept has a polymer dome enclosing the dish (see Figure 2).

A systems engineering study was performed to identify problem areas and research issues, and to study technical feasibility as well as performance and areas likely to drive the cost up. We reviewed previous thermal dish development and cost and systems studies; analyzed, assessed, and recommended solutions for numerous limiting thermal performance issues; and established bounds for likely dish costs. Performance models were developed and used for the trade off studies. Finally, conceptual designs for reconfigured dishes and receivers were developed.

Analysis findings indicated that this concept is feasible. There are, however, numerous technical challenges that must be overcome. In addition to the issues identified with polymer-enclosed heliostats, the major technical problem appears to be the "beam walk-off problem" where the beam is no longer focused at the receiver but at some other point, which can result in exceedingly high flux levels on the dome enclosure. This can be caused by malfunctions in the tracking mechanism or by intentionally moving the dish off focus during maintenance.

Also, in moving toward low-cost dish concepts, we found that a much smaller focal-length-to-diameter ratio (f/D) [i.e., about 0.25 versus about 0.60 for current designs (see Figure 3)] is desirable to reduce the structural weight associated with both the dish and the strucutral support of the receiver and to take advantage of the additional strength of the resulting enhanced curvature effects. Further, the smaller f/D dishes allow smaller enclosure diameters while still solving the beam walk-off problem (see Table 1).

Reconfiguration of the smaller f/D concept requires an external receiver. However, the external receiver can be smaller, lighter, and less expensive than a corresponding cavity receiver. Thus, using this smaller external receiver can partly compensate for the lower efficiency of the external receiver. Furthermore, by using selective coatings, analysis has shown that the performance of the external receiver can be fairly close to that for a cavity up to temperatures of 540°C (1000°F). Moreover, an evacuated enclosure looks feasible and can improve the performance even more. Note that for temperatures significantly above 540°C (1000°F), the external receiver will not perform as well as the internal cavity receiver. Also, the external receiver, if optimized for high efficiency and with the smaller f/D ratio dish, appears to have merit whether the dish is enclosed or not and possibly can be used for electric applications using existing materials and current Rankine-cycle steam technology.

Systems analyses show that the reconfigured enclosed dish is potentially more cost-effective on annual cost of delivered energy basis compared with the unenclosed conventional dish. However, the benefits of the enclosed thermal dish are not enough to make thermal dishes more cost-effective than some other solar thermal technologies (i.e., central receiver) above the 5-MW size range. Based on standard economic assumptions the delivered energy costs for dish systems (whether enclosed or not) appear to be 50%-100% greater than for central receivers using second-generation glass and metal heliostats for 5-MW or larger sizes. However, for very small sizes, other issues may lead to the selection of dishes. For instance, utilities are interested in very small modular applications of dish technology because of the lower capital cost and the potential to incrementally add to the generating capacity of the system.

Systems analyses also show that thermal transport costs for thermal dishes are exceedingly high using current technology or anticipated advances of this technology in the near term. These transport costs alone may exceed the value-based cost goal levels set in 1981 for collector subsystems. Polymer enclosures aggravate these already high costs for transport, and, thus, some of the anticipated advantages of enclosures are lost.

The results from the analysis of the enclosed dish concept indicate that the enclosure concept itself does not appear to merit strong continued research emphasis. However, the lower f/D dish concept with an external receiver appears to have significant merit whether the dish is enclosed or not, up to operating temperatures of 540°C (1000°F). Clearly, a range of materials, thermal, structural, and systems research issues remain to develop the "deep dish" concept and to verify its potential. These include those issues related to receiver coatings, small external boiler receivers, low-cost, accurate deep profile shell structures, and much improved transport subsystems.

REFERENCES

1. Edelstein, R. et al., Final Presentation of the Solar Thermal Cost Goals Committee, presented to the U.S. Department of Energy, Washington, D.C., 26 February 1982.

2. Murphy, L. M., Technical and Cost Benefits of Lightweight, Stretched-Membrane Heliostats, SERI/TR-253-1818, Golden, CO: Solar Energy Research Institute, 1983.

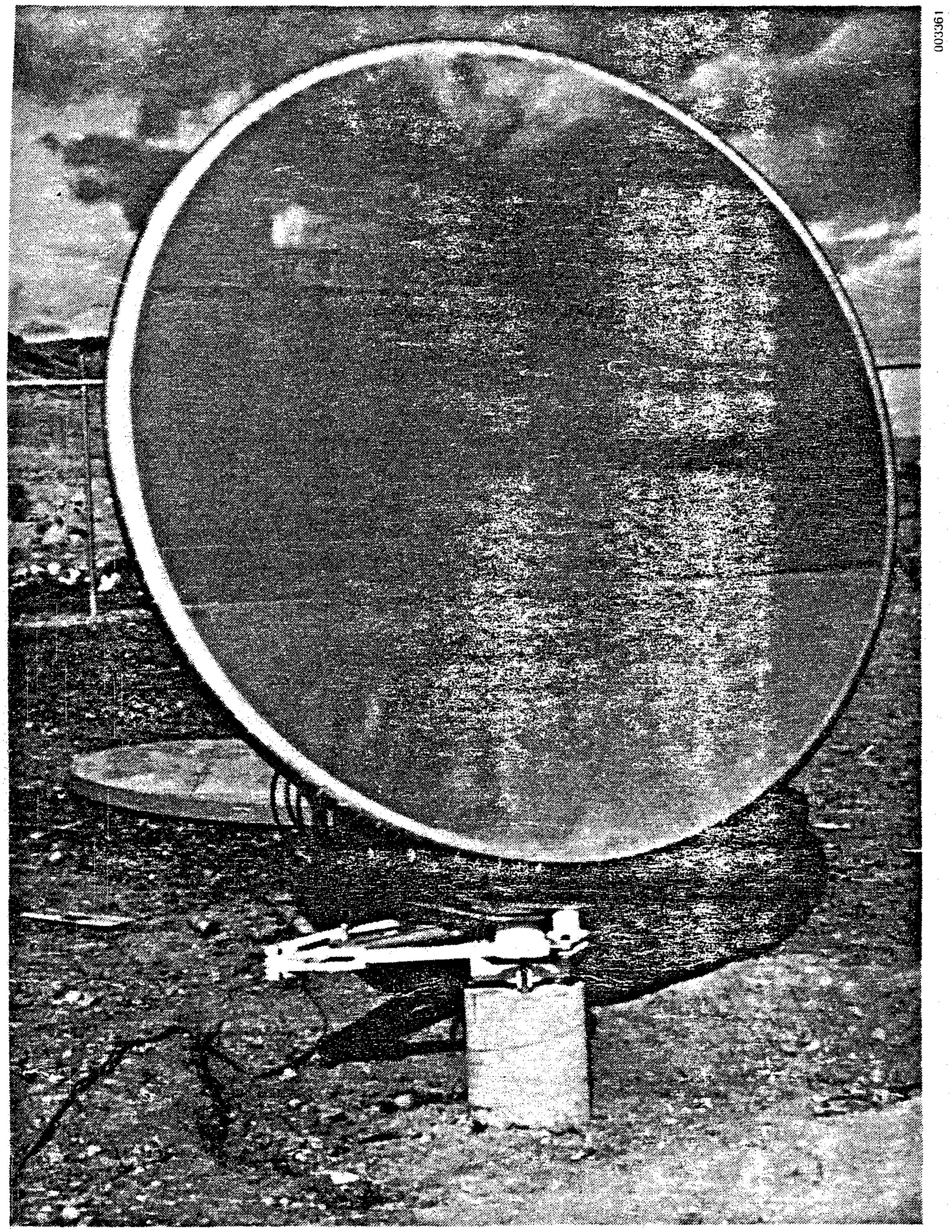

Figure 1. Two-Meter Diameter, Stretched-Membrane Heliostat Research Experiment at the SERI Test Site

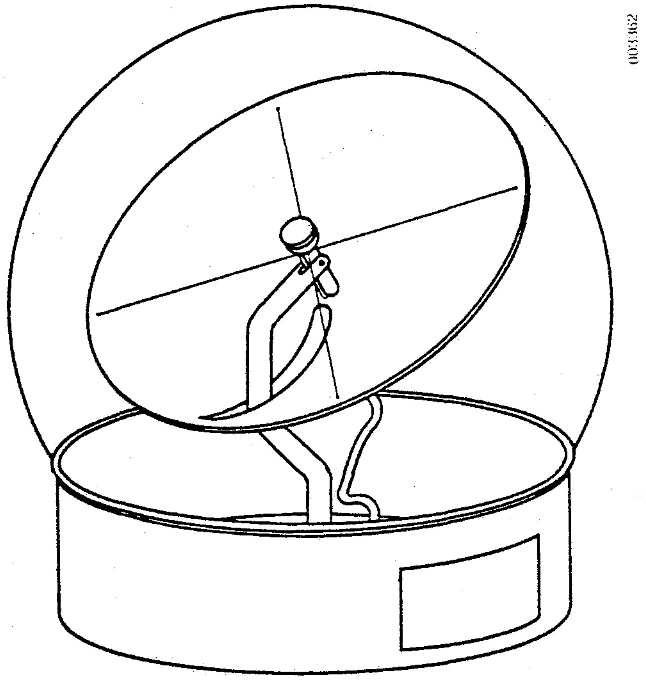

Figure 2. Conceptual Design of a Polymer-Enclosed Thermal Dish Having a Small f/D, an External Receiver, and a Single Post Receiver Support

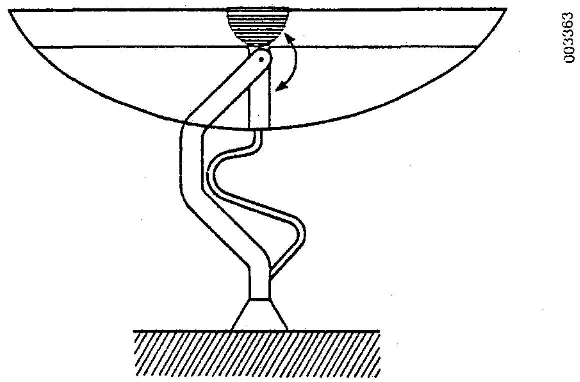

Figure 3. Side Section of a Deep Profile Thermal Dish (f/D = 0.25) Conceptual Design

Table 1. Various Dome Geometric and Flux Requirement Parameters Shown for Several Polymer-Enclosed Dish Geometries. Note that for f/D = 0.60, a dome diameter three times as large as the dish is required to assure that the most severe flux on the enclosure surface is at or below 15 suns. For f/D = 0.25, a dome only 30% larger than the dish is required.

DISH DIAMETER, M	10	10	10
FOCAL LENGTH, M	9	6	2.5
RIM ANGLE, °	31	45	90
MINIMUM DOME RADIUS BASED ON GEOMETRY, M	9	6	5.6
$\frac{\text{MINIMUM DOME DIAMETER}}{\text{DISH DIAMETER}}$	1.8	1.2	1.1
WORST CASE FLUX AT 1.1 X MINIMUM DOME DIAMETER	267	260	16
MINIMUM DOME DIAMETER TO GET 15X CONCENTRATION, M	41	29	13