SOLAR DRYING OF AGROCULTURAL PRODUCTS

by

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ABSTRACT

Research in agricultural applications of solar energy is receiving considerable attention in North America and in many other countries such as Italy and Brazil.This renewed interest stems from the fact that the prospects for growth is limited to the explotation and development of available energy resources. Additionally, the harnessing of solar energy is based on simple inexpensive technologies.

This paper reviews the programmes on three fundamental designs, validation of simulation models and the research results of the drying of cereal grains with solar energy as applied in North America. The availability of construction material and the variation in the meteorological conditions will result in varied approaches. The conclusions reached in this study are:

1) Solar grain dryers cost in the range of \$ 1.50 to \$ 3.50 per square foot.
2) The rectangular shaped solar collectors built qith readily available materials are the mos efficient.
3) Solar drying is economically viable.
4) The practical problems associated with the portable, plastic reinforced designs integrated with low efficiencies, limits their usefulness, as a reliable solar collector.
5) Solar drying simulated models presented by Thompson and Bakker-Arkema are in reasonable agreement with experimental data.

INTRODUCTION

Several reasons have been put forward for solar drying of highmoisture content agricultural products. Some of the reasons are:

i) reduce the comsuption of expensive, imported fossil fuels,
ii) eliminate the need to transport the excess water contained withing the produce,
iii) enhance the prospects of new exportable items,
iv) minimize losses during the store period,
v) improve the quality of grain by reducing the level of traditional toxic producing organisms,
vi) increse the potential of second cropping and,
vii) reduce dust and insect infestation.

Since solar energy is essentially a low temperature heat source on the surface of the earth, it is suitable for drying of agricultural produce.With some produce, such as fruits, temperature control is essential(1) whereas for wheat, the input drying temperature should be maintained below a maximun value(2). These constraints do not limit the use of the low temperature method wherein large quantities of air , a few degrees Centrigrade above ambient conditions, are provided before any damaging deterioration occurs. Furthermore, since solar drying technology is simple, inexpensive, and easily adaptable to agricultural uses (3), it will undoubtedly receive high priority as an area of research. The basic principles underlying solar grain drying are well understood (4). The methodology is linked to the meteorological conditions and the availability of construction materials and technology in a particular country. Hence, there is a need to analyze the type of systems presently used. This is the main emphasis of this paper.

WORLD EXPERIENCE

The rate of growth of the word's population, double within the next thirty years, requires not only an increase in food production but also a preservation of agricultural surpluses at the time of harvest.It is not possible to describe the experiences of the many countries who are at present experimenting with solar drying. Table 1 lists some of these countries. This drying process, in addition to minimizing losses during the stored period,enables farmers to harvest additional cuantities of crops that would otherwise go to waste. Thus, drying is one means of exploiting the world's farm land capacity.The reasons put forward by industrialized nations are, in many cases, the same as those put forward by the less-industrialized nations can be found in references (3), (5) and (6).

UNITED STATES AND CANADIAN SCENE

In the United States, the public and private sectors in the agricultural community realized that conventional dryers are energy intensive and the operational costs will be increasingly effected by the growing fuel shortage. Agriculture consumes about 2 percent of the total energy in the United States, principally in the form of liquified petroleum gas (LPG), and estimates are that as much as 50 percent of this energy can be replaced by solar energy in the year 2020. A summary of the agricultural research projects supported by the U.S.Energy Research and Development Administration(ERDA), are listed in Table 2. The overall objective of the programme is to develope and demonstrate solar energy technology in agriculture, throughout the U.S. so as to reduce dependency on fossil fuels. Through the Agricultural Research Service (ARS), the State Agricultural Experimental Station (SAES), industry and univeristies, experimentation has been involved in the following areas:

i) solar grain drying,
ii) solar drying of peanuts, forage and tobacco,
iii) solar energy in livestocl shelters and,
iv) solar heating and cooling of greenhouses and rural residences.

The project coordinator for ERDA is Mr William R.Cherry, Division of Solar Energy Research, ERDA, Washington D.C., 20545 and the project coordinator for ARS-USDA is Dr.Landy B.Altman, Room 219 North Building, Agricultural Research Center-West, Beltsville, Maryland,20706.
The principal investigator for ARS-USDA is Dr.George Foster(address in Table

2) and the co-principal investigator for SAES is Dr.Robert M.Peart(address in Table 2).

In 1975 the grain drying programmes received a total of $ 300.000.- out of a possible $ 1.500.000.- which was allocated to agricultural applications of solar energy for heating and cooling. In 1977 the sum of money for grain drying reached a value equal to $ 530.00.-(7).

Although the amount of research funds for solar drying in Canadá is significantly less, the aims and objetives remain the same.Of particular interest is the research project presently underway in Saskatchewan. This project is a joint cooperation between this author, the Agricultural Engineering Services Branch of the Saskatchewan Department of Agriculture and the Agriculture Canadian Research Experimental Station in Swift Current. Saskatchewan. The experimental site is located in Swift Current.

SOLAR COLLECTORS FOR GRAIN DRYING

BARE PLATE COLLECTOR

Bare flat plate collectors are simple in design and construction, since they consist of a space for air flow between the absorbing surface and the insulated or noninsulated backing of the bare plate, e.g., galvanized iron sheeting painted black, is lost since it is reradiated to the atmosphere. The wind blowing along the absorbing surface, also reduces the efficiency of this collector(3). Despite the fact that the bare flat plate collector is inefficient, it is an inexpensive, simple collector to construct with materials in inventory. Additionally, it can be attached to a standard grain bin by the construction of a secondary black surfaced wall around the bin(3), or by the construction of an additional surface on existing buildings (3).

COVERED PLATE COLLECTOR

The covered flat plate collector differs form the bare plate collector by the addition of a clear cover (Figure 2). The cover transmits radiation from the sun and is essentially opaque to the longer wave length energy emitted by the absorbing plate. The cover plate also reduces energy losses by convection As the air passes between the cover plate and the absorber, the enthalphy increases(increase in temperature) and this heated air can be used in the solar drying process.The number of covers need not be restricted to unity.

SUSPENDED FLAT PLATE COLLECTOR

A third configuration of a flat plate collector is shown in Figure 3. Air flows on both sides of the absorber, hence the efficiency(defined later) of this type of collector is increased. Although construction is still simple, the costs are somewhat higher than the proceeding two types of flat plate collectors. The user must decide between a high efficient more expensive collector or a low cost, less efficient collector.

For fixed ambient conditions, air flow rate and exit temperature the less efficient unit requires more surfaca area hence, there is a trade off between a large inefficient unit and a smaller more efficient unit.

EFFICIENCY

The efficiency of a collector is measured by the ratio of the actual increase

in enthalphy of the air that passes through the collector to the available energy. For a given configuration, as the mass flow rate increases, at a fixed level of solar radiation, the temperature of the air decreases. Also, for all conditions remaining fixed the efficiency of the system can be increased by inducing turbulent flow. This can be achieved by the use of increased air flow rate, by an appropriately designed collector or by the use of an irregularly shaped absorbing surface. The efficiency of several types of collectors are given in Table 3, as well as the type of material used in construction. Consideration of efficiency is not the only factor that must be analyzed. One must carefully consider the capital cost, annual costs, reliability, simplicity, portability, multiple use, etc.
This paper does not adress itself to these questions, but these considerations may, in the end, bu more important than consideration of solar collector efficiency alone.

SASKATCHEWAN EXPERIENCE

Since the province of Saskatchewan produces most of the wheat in Canada and drying, particularly in the Northern grain belt, must be done, on the average once out of every two years, solar grain drying may play a significant role in reducing fossil fuel consumption and saving the farmers money in the long term. Based on this, a solar collector(Figures 4 and 5) was constructed in the fall of 1977 at the 53°latitude, with materials in inventory. Construction time was only two days, and fifty tonnes of wheat were dried from 16.5 percent to 14.5 percent moisture content in three weeks. More importantly it was concluded that solar grain drying competes economically with mechanical methods (10).

MATHEMATICAL MODELLING

There are several mathematical models that describe the physical situation of removal of water from cereal grains. These are classified as being thermal electric (12), algebraic(13), or simulated (14).
One can conlude, by analyzing weather data alone, that tough, damp grain can be cooled and dried by ventilation with ambient air. This however, does not define the performence of a low-temperature drying system under a given set of input data. Furthermore, the required time for drying is not defined by the analysis. Mathematical models are there fore used to predict changes in moisture content, temperature and grain condition drying period.
The thermal-electric system (12) considers the three modes of heat transfer in working out the thermal circuit. Preliminary results showed that this method provided an effective means of studying the timevariant thermal behavior of a solar drying system. The usefulness of this system is somewhat questionable, since it is not based on the fundamental laws of heat and mass transfer.
A simulation model(14), based on heat and mass transfer principles, allows for predicting heating or cooling in drying or moisture absorption processes for any biological product, provided the basic assumptions made in the deviation of the model are satisfied. A detailded review of these models has been divided into four categories, (i) the fixed bed dryer, (ii) the crossflow dryer, (iii) te concurrent dryer, and (iv) the countercurrent dryer. The use of 24 hour time averaging of weather data saves computer time and appears to

be acceptable for low-temperature drying(15). Although the predicted moisture content and dry matter losses are underestimated due to averaging, this technique is acceptable for most grain drying simulation studies. Mathematic relationships describing the drying of capillary porous products are discussed by Bakker-Arkema(14). The time dependent equation for mass transfer within the kernal is simplified by neglecting temperature and pressure gradients; however, this simplified equation has led to stability problems in the numerical solution. As a result, several empirical drying equations have been developed(16), (17).

A low-temperature, low air-flow drying model developed by Thompson (13) has also been used for simulating deep bed drying processes. Validation procedures have resulted in several modifications to this model(18) A critical factor in evaluating the performance of low-temperature drying systems is the ability to predict quality deterioration as influenced by growth and respiration of mold and fungi in the grain mass. Thompson's model is conservative in this regard.

SUMMARY

1. The cost of solar collectors vary from \$1.50 to \$3.50 per square foot and can be made from materials that are readily available and with little technical knowledge.
2. The use of solar drying can improve the quality of cereal grains and reduces the losses incurred during the storage period.
3. Solar collectors have the capability of reducing the consumption of fossil fuels.
4. The plastic reinforced solar collectors may have usefulness due to their portability but their cost effectiveness and reliability has to be improved by further development and experimentation.

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TABLE 1

INTERNATIONAL USES OF SOLAR DRYING

COUNTRY	SOLAR DRYING
Argentina	fruits, vegetables
Australia	timber, grapes, corn.
Austria	tobacco
Brazil	cocao, fruits,"carrioca" dry beans, banana.
Columbia	cassava, coffee beans.
Costa Rica	vegetables.
England	cereals.
India	fruits, vegetables, chillies, timber.
Irán	fruits, vegetables.
Italy	fruits, vegetables.
Jamaica	crops.
Japan	fruits, vegetables, grain,timber.
Jordon	general.
Mexico	grain.
Nigeria	grain.
Pakistan	fish.
Philippines	general.
Puerto Rico	coffee beans.
Saudi Arabia	general
Sweden	hay, grain.
Turkey	fruits, vegetables.
URSS	fruit.
West Indies	fruits, vegetables.

TABLE 2

Summary of Agricultural Research Projects Supported by the U.S. Energy Research and Development Administration.

Solar Drying of Peanuts, Forage and Tobacco

PROJECT MANAGER	LOCATION
Mr.Nat K.Person, Jr.	Department of Agricultural Engineering, Texas A&M University College Station,Texas, 77843.
Dr.B.L.Clary	Agricultural Engineering Dept. Oklahoma State University Stillwater, Oklahoma, 74074.
Dr.J.L.Butler	ARS-USDA Costal Plain Experimental Stn. Tifton, Georgia, 31794
Dr.L.R.Walton	ARS-USDA University of Kentucky Lexington, Kentucky, 40506
Dr.B.K.Huang	Professor of Biological & Agricultural Engineering North Carolina State University Raleigh, North Carolina, 27607.

Dr.B.L.Bledsoe	Department of Agricultural Engineering Tennessee Agricultural Experimental Station Knoxville, Georgia, 37901
Dr.A.P.Sheppard	Associate Vice President for Research Georgia Institute of Technology Atlanta, Georgia, 30332
Dr.S.V. Bourgeois	Lockhead Missiles & Space Co.Inc., Huntsville Research & Engineering Center 4800 Bradford Drive Huntsville, Alabama, 35807

Solar Grain Drying

Dr.R.W.Hansen	Department of Agricultural Engineering Colorado State University Ft.Collins, Colorado, 80523
Dr.G.C.Shove	Department of Agricultural Engineering University of Illinois Urbana, Illinois, 61801
Dr.R.M.Peart	Department of Agricultural Engineering Purdue University Lafayette, Indiana, 47907.

Dr.R.I.Lipper
Department of Agricultural
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Kansas State University
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Dr.F.W.Bakker-Arkema
Department of Agricultural
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Michigan State University
East Lansing, Michigan, 48824

Dr.V.Morey
Department of Agricultural
Engineering
University of Minnesota
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Dr.D.B. Brooker
Department of Agricultural
Engineering
University of Missouri
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Dr.H.M Kenner
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Mr.J.R.Barrett
Agricultural Research Service USDA
Department of Agricultural
Engineering
Purdue University
Lafayette, Indiana, 47907

Mr.G.L.Kline	Agricultural Research Service,USDA Agricultural Engineering Dept. Iowa State University Ames, Iowa, 50010
Mr.D.L.Calderwood	Agricultural Research Service,USDA Texas A&M University Research and Extension Center Route 5, Box 366 Beaumont, Texas, 77706
Dr.G.H.Foster	Agricultural Research Service,USDA Grain Marketing Research Center Manhattan, Kansas, 66502

Solar Energy in Livestock Shelters

Dr.P.D.Thompson	USDA Genetics and Management Laboratory Beltsville, Maryland, 20705
Dr.J.L.Cain	University of Maryland College Park, Maryland 20742
Dr.L.N.Drury	USDA Southeast Poultry Research Laboratory 934 College Station Road Athens, Georgia, 30601
Dr.R.N.Brewer	Auburn University Auburn, Alabama, 36830

Dr.W.H.Brown	Mississippi State University Mississippi State, Mississippi 39762
Dr.F.N.Reece	USDA South Central Poultry Research Laboratory PO Box 5367 Mississippi State, Mississippi 39763
Dr.K.L.Mc Fate	University of Missouri Columbia, Missouri, 65201
Dr.C.K.Spillman	Kansas State University Manhattan, Kansas, 66502
Dr.J.De Shazer	University of Nebraska Lincoln, Nebraska, 68503
Dr.D.H. Vaughan	Virginia Polytechnic and State University Blacksburg, Virginia, 24061
Dr.B. Horsfield	University of California Dept of Agricultural Engineering Davis, California, 95616

Solar Heating & Cooling of Greenhouses and Rural Residences

Dr. W.J. Roberts	Dept of Biological & Agricultural Engineering Rutgers University New Brunswick, New Jersey, 08903

Dr.C.N. Hodges	Environmetal Research Laboratory University of Arizona Tucson, Arizona, 85721
Dr.T.E. Bond	Rural Housing Research Unit, ARS/USDA PO Box 792 Clemson, S.Carolina, 29631
Mr.R.C.Liu	USDA/ARS Building 046-A Beltsville, Maryland, 20705
Dr.J.N.Walker	Department of Agricultural Engineering University of Kentucky Lexington, Kentucky, 40506
Dr.T.H.Short	Department of Agricultural Engineering Ohio Agricultural Research and Development Center Wooster, Ohio, 44691
Dr.D.R.Price	Department of Agricultural Engineering Cornell University Ithaca, New York, 14853
Dr.J.H.White	Horticulture Department Pennsylvania State University University Park, Pennsylvania, 16802

TABLE 3

EXPERIMENTAL EFFICIENCY OF SOLAR COLLECTORS

SHAPE	COVER PLATE	ABSORBER	BACK PLATE	COLLECTOR EFFICIENCY( )	
	bare	polyethylene	none	14	*
	polyethylene	polyethylene	ground	12	*
	polyethylene	polyethylene	polyethylene	24	*
	bare	metal	plywood	12	*
	plexiglass	plywood	none	22	*
	fibreglass	plywood (insulated)	none	34	*
	polyethylene	polyethylene	plywood	36	*
	glass	metal	plywood (insulated)	55	*
	fibreglass	60°metal	plywood (insulated)	62	*
	polyethylene	polyethylene	ground	35-56	**
	various	grain bin	grain bin	13.5-90	***
	polyethylene	polyethylene	ground	39	+

\+ Tested by Morey at University of Minesota over a 28 day period.

* measured for 15 full days during the fall and winter 1975-76 with the collectors facing South at an optimum noon angle, air flow rate of 0.31 m^3/min. per m^2 , clear to partly cloudy skies, in Ames, Iowa.

** Tested at Woster, Ohio at various air flow rates with the back plate being either insulated or noninsulated and the orientation being either N-S or E-W.

***for details see reference (11)

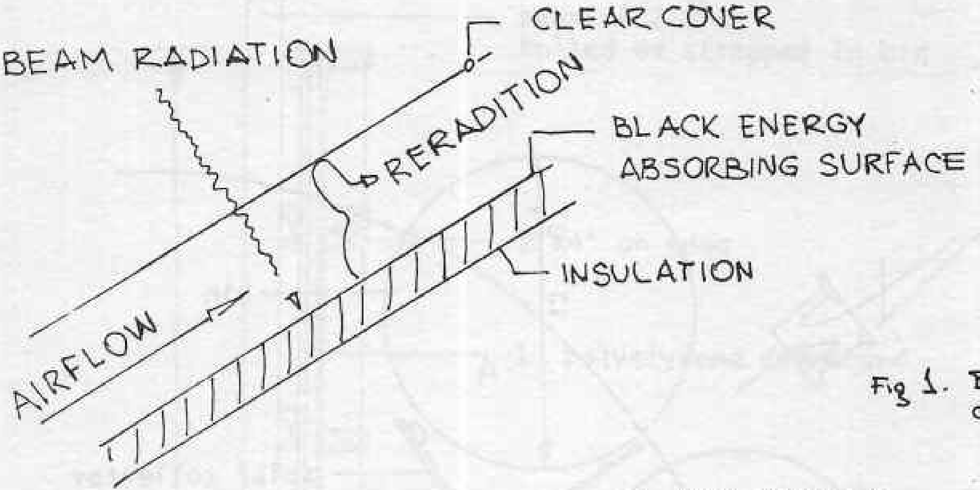

Fig 1. Bare plate collector

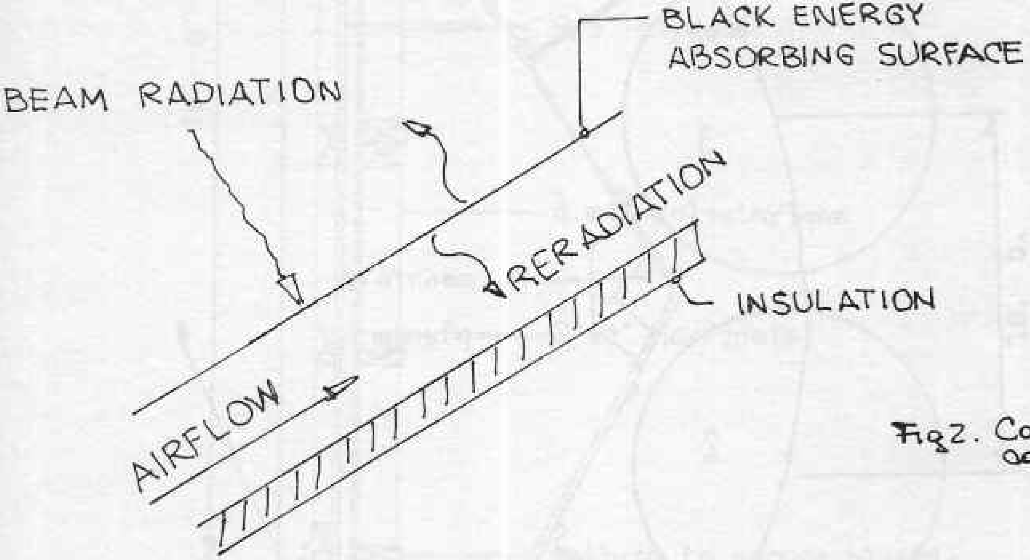

Fig 2. Covered plate collector

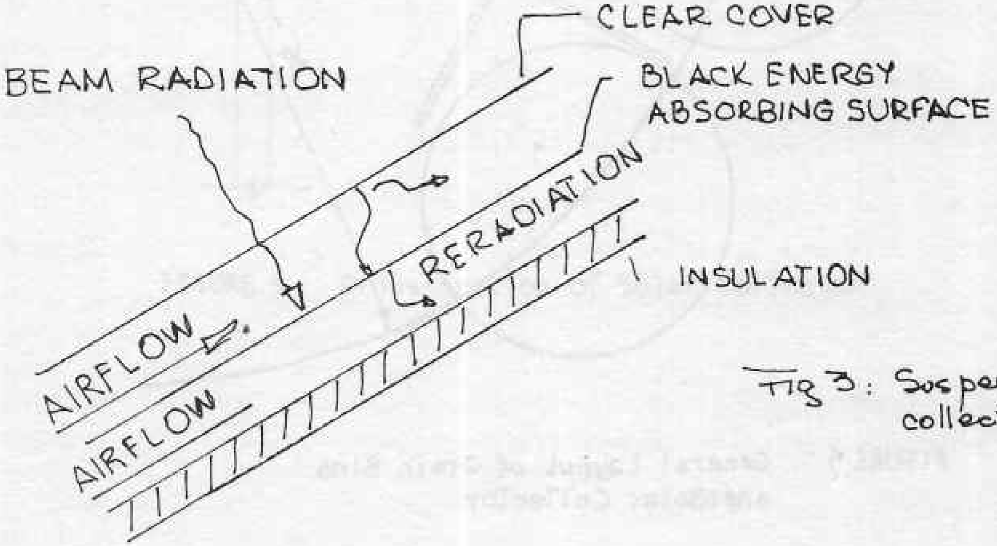

Fig 3: Suspended plate collector.

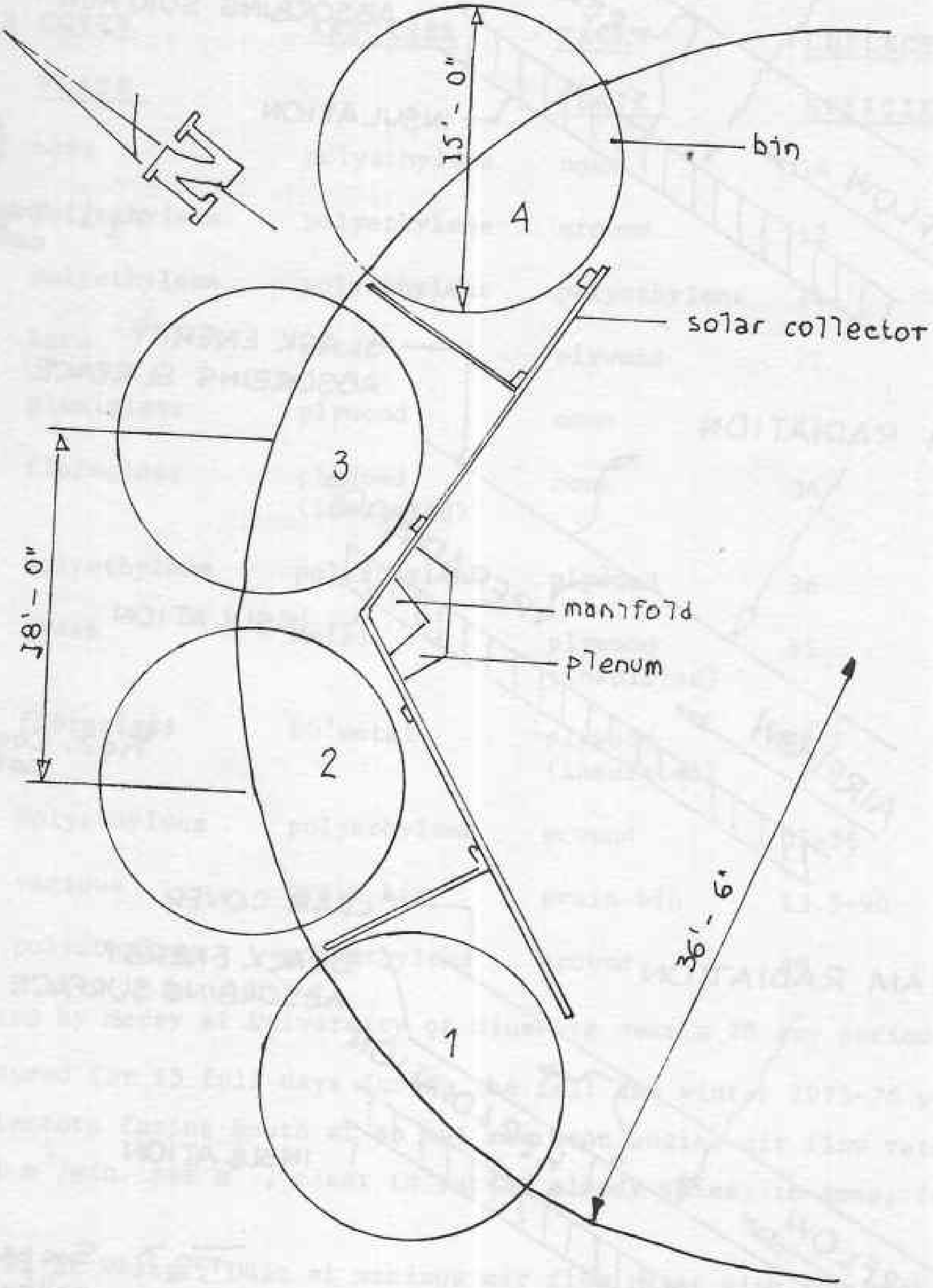

FIGURE 4 General Layout of Grain Bins and Solar Collector

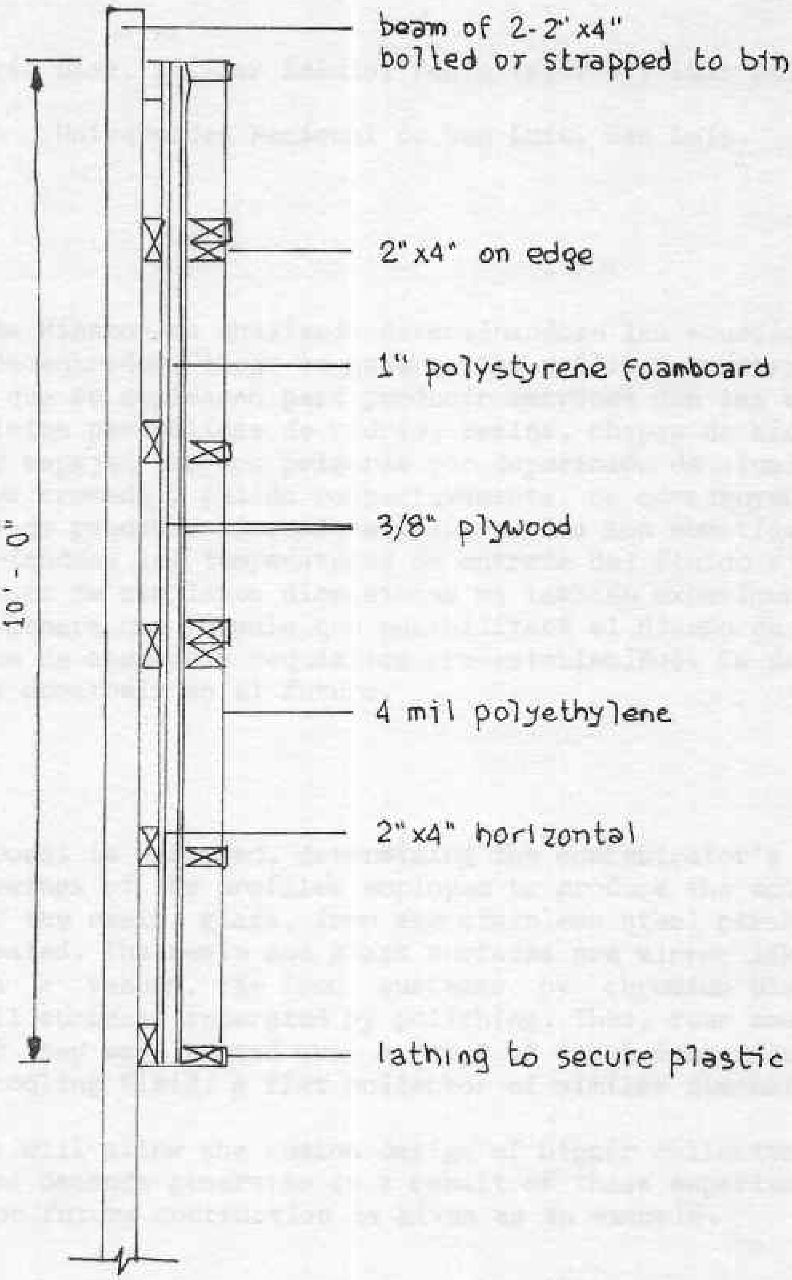

FIGURE 5 Cross-section of Solar Collector