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MILITARY TECHNICAL COLLEGE

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New Development in the Design and Production of Solar Collectors

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ABSTRACT

New designs and production methods are used to manufacture cost effective flat solar collectors, using local materials and simple fabrication techniques. This is applied to absorber plate, collector cover, brazing, soldering and adhesive materials, the insulation and the casing as well. The different joints of the absorber are subjected to thermal cycling to determine the fatigue limit and therefore the lifetime of the absorber plate. The developed collectors are tested in a test rig to evaluate their performance and thermal efficiency

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1. Introduction

With the ever increasing cost of conventional energy and the growing concern about our national energy reserves of depletable fossil fuel,efforts are now being directed towards the development of nonconventional energy sources such as solar and wind energy.
The potential of wind energy utilization in Egypt is largely restricted to the Red Sea and the Mediterranean Sea coasts.

As for solar energy,Egypt lies within the sub-tropical region in the Northern Hemisphere (31° - 22°N).It is one of the countries which has the most sun-shining hours per year, ranging from 3000 to 4000 hours.On the other hand,the total solar intensity incident on a horizontal surface ranges from 4.6 to 8.4 KWh/m^2 day at lower Egypt and from 7.2 to 10.8 KWh/m^2 day at upper Egypt. There is a great potential in the utilization of solar energy either for electricity production or in thermal systems.However,the immediate application of solar energy should be in thermal systems.These systems have two main adventages.
First,the technological know-how required for the production of such systems seems to be fairly well established.Secondly, from a thermodynamic point of view,these systems have a unique and most attractive feature which is the feasibility of matching a means of collection to a broad range of tasks which operate over a large range of temperatures.This argument can be further understood by assigning a quality index to energy.The concept of available energy,i.e.,energy available to do work,the most valuable form of energy,provides a useful messure of energy quality.With this concept it is possible to analyze means to minimize the consumption of available energy to perform a given process,thereby ensuring the most efficient possible conversion of energy for the required task.Using the concept of availability,it is possible to define a second-law efficiency η_2 of a process as the ratio of the minimum available energy which must be consumed in performing the task.The second-law efficiency is a task index not a device index.It is therefore much more useful in identifying optimal energy conversion processes since it focuses attention on device interactions that transform energy into its useful types - work and heat.
In a gas water heating system designed to heat water up to a temperature of 60°C assuming the gas furnace efficiency of 65 °/o,the second-law efficiency η_2 = 8,5 °/o while that of a solar enrgy system will be 80°/o .
Broadly,solar thermal systems can be classified according to temperature level as :

- low temperature systems: $<$ 150°C ,
- medium temperature systems 150°C to 300°C ,
- high temperature systems $>$ 300°C ,

or according to working fluid such as: air,water,oils or molten metalls,
or according to design features: planar,liner focusing or spot focusing.
Thermal energy in industrial processes is required in the

form of steam,hot water or hot air for industries such as food processing and canning,textile industry,crop drying,chemical industries (plastics,soap and organic dyes),and petroleum refining (preheating of crude oil prior to distallation).

Most of the part of the thermal energy used in industry is at temperatures below 250°C.

The Egyptian Government subsidy for fuels used for heating purposes ran for over 600 million pounds a year.Furthermore most of the thermal energy required can either be supplied by solar systems or solar assisted systems thus achieving a significant saving in fuel consumption.The importance of introducing solar thermal systems into Egypt is thus of great urgency.

The technology of solar thermal systems is fairly well established in many countries and solar systems are now in use for both domestic and industrial process heating.In Egypt,the solar water and air heating industry is still in its infancy and extensive work is needed in order to develop our own technology,since the impact of introducing such system in Egypt is very promising.

1.1 Solar Collector Features

A solar collector is a device for intercepting solar radiation,making use of it to heat a fluid and delivering the heated fluid for use.
It is a special kind of heat exchanger that transforms solar radiant energy into heat.The flux of incident radiation is,at best,approximately 1100W/m^2 and is variable.The wave length range is from 0.29 to 2.5 µm.If the surface on which solar radiation is absorbed has an area approximately equal to the area exposed to the sun's rays,the collector is of the non-concentrating type.The solar absorbing surfaces in most non-concentrating collectors are substantially flat.
Flat plate collectors can be designed for applications requiring energy delivery at moderate temperatures up to 100°C above ambient temperature.They use both beam and diffuse solar radiation,and do not require in most cases tilt angle readjustment.
The wide variety of applications for low temperature water and air heating systems both for domestic and industrial process heating gives priority for the development of such systems.

2. Research Objectives

The direct objective of this research is to design and produce flat solar collectors to make use of the abundant solar radiation,in which Egypt is rich,and convert it into a clean, inexpensive usable energy.
Efforts are directed to the use of local technology as regards materials,fabricating techniques and design features of the collectors.
Local materials are carefully selected and developed to achieve highest thermal performance of the collectors.Adequate ma-

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nufacturing techniques have been investigated and developed to achieve easiest production and highest efficiency of collectors.Of course,High efficiency and low cost are not independent and have to be optimized according to system requirements so that collectors developed would be cost effective.

Another important aspect is the durability of the developed collectors.The most cost effective thermal systems are those with the longest life-time.Therefore,the design effort in this research has been directed to achieve a maximum increase in life-time with minimum cost.

3. Design Aspects

The main parts of a typical liquid flat plate collector,as shown in Figure 1,are the black solar energy absorbing surface with means for transferring the absorbed energy to a fluid covers transparent to solar radiation over the solar absorber surface that reduce convection and radiation losses to the atmosphere,and back insulation to reduce conduction losses. It is therefore,the absorber that is considered to be the most vital part of the collector and accordingly it deserves careful attention in this work.

3.1 Materials

Research efforts are directed to find local material or develop new ones most suitable for the design and production of the different parts of the solar collector.For the absorber, such materials should achieve an optimum combination of the following desirable properties

1. High thermal conductivity
2. High corrosion resistance
3. High thermal fatigue resistance
4. Reasonable strength
5. Light weight
6. Availability in local market
7. Low cost

Several candidate materials were selected in this research work namely:

1. Copper
2. Aluminium alloys
3. Composite adhesives
4. Polyester fiber glass
5. Teflon foils

In the absorber design the following aspects are aimed : All th piping of the absorber i.e. the risers and headers are made of thin copper tubes,while the fins are made either of thin copper or aluminium foils.These should be in firm contact with the riser tubes in order to ensure maximum heat transfer.This is conventionally achieved by brazing or soldering.

In order to simplify and reduce cost of production,beside avoiding corrosion problems,brazing and soldering should,as far as possible,be avoided in the fabrication of the absorber and the collector as well.Instead of the costly brazing or soldering.mechanical seams and adhesion joining are intro-

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duced in these joints. However,the joining through mechanical seams and adhesion,should realise good heat conducting contact between the fins and riser tubes,beside non leaking brazed joints between risers and headers.In order to investigate the durability of these joints,they are subjected to thermal cycling.between room temperature and 90°C .The test rigwhich is sketched in Fig. 2,enables two test specimens to be investigated at the same time,one is dipped in a cold water bath for 30 s,while the second one is dipped at the same time and for the same period in a hot bath.Then they exchange their places periodically every 30 s .

4. Developed Design and Manufacturing Methods of the Absorber Panels

4.1 The Different Desings of Riser Tubes and Fins

4.1.1 Fig. 3 shows the 1st design where the fins are made of thin foils 0,2 mm copper or 0,5 mm Aluminium surrounding the riser pipes.The joining of the fin edges is achieved by means of mechanical seams,which are tightend by rolling in order to ensure better contact with the riser tubes.

4.1.2 In the 2nd design,a special fin form is developed to make the utmost use of incident solar radiation on the absorber resulting in a better thermal performance.The fins are inclined by different angles to be favourably oriented to the incident radiation according to the apparent path of sun over the whole day as dipicted in Fig. 4 .The joining between the absorber fins and the riser tubes is achieved by means of self clamping terminals formed in the fins,Fig. 5 .

4.1.3 The 3rd design features another mechanical clamping method between the fins and the riser tubes.The fins either copper or aluminium,are rounded by means of a system dies as shown in Fig. 6 .The rounding forms a cylindrical bend with a diameter slightly less than that of the riser tube outer diameter.Hence,inserting the riser tube into these cylindrical bends will cause them to clip on the riser tubes,thus providing an efficient contact.

4.1.4 The 4th design aims at simplifying the shape of the fins and production procedure and consequently reduce the cost. Fig. 7 illustrates this design,which depends upon forming a semi-cylindrical depression in the fins by pressing a round steel bar on it using a timber die.The fins are joined to the riser tubes by means of a self developed heat conductive adhesive. Two types of heat composite conductive adhesives were locally developed.The first is composed of Epoxy binder mixed with a certain percentage of Al-powder.The curing time of this binder is accelerated by a curing agent (hardener).In the second binder the Al-powder filler material is replaced by graphite powder.The last binder has proved to be very successful and therefore is used in producing two absorber panels.In the first copper fins are used, while Aluminium foils as fins are in the second panel.

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4.1.5 The 5th design is similar to the fourth design already described in 4.1.4 .Instead of joining the fins to the riser tubes by means of adhesion,soldering is used for the copper fins as well as for aluminium fins in which special flux is used to facilitate wetting action during soldering.

4.1.6 The main features of the 6th design is based on the use of copper or aluminium sheet strips as absorber fins with collared holes near one end,and having a diameter slightly less than that of the riser tubes outer diameter. These strips are curved and assembled with the riser tubes by force fitting,Fig.8 .

4.1.7 The design and production of the 7th absorber panel is a little bit extraordinary in its features.The fins are completely eliminated and are replaced by transparent glass tubes,coated from the inside with a mirror silver precipitate layer to an angle of 170^{o} of its circumference.These glass tubes are cored coaxially with the riser tubes,so that their 190^{o}angle transparent surfaces are directed towards the front side of collector allowing incident solar radiation to directly heat the riser tubes.The remaining area of the mirror glass tubes corresponding to an angle of 170^{o} reflects and concentrates the rest of the falling rays back to the risers,Fig. 9 .

4.1.8 The 8th design is similar to that of the last absorber No. 7 explained in (4.1.7),but the reflecting glass tubes are replaced by parabolic reflectors made of timber coated with aluminium foil.The riser tubes are then placed in the focci of the parabolic reflectors,Fig. 10 .

4.1.9 The design of the 9th absorber panel depends upon eliminating the absorber fins by deforming the cylindrical copper riser tubes to have an elliptical form, Fig. 11 . However,both ends of the riser tubes remain cylindrical to facilitate joining with the headers by brazing.

4.1.10 The absorber panel No. 10 is made of plastic piping and fittings to reduce the cost and weight and to simplify production.The risers are made of dense polyethylene (HDPL) that contains about 2°/o carbon black to increase absorbivity and resistance to degradation under the effect of prolonged exposure to the sun.The risers are closely spaced and therefore the fins are not more needed.
The haders are made of dense Polypropelene PP . Joining between risers and headers will be through compression fittings.

4.1.11 In the 11th absorber panel two stainless steel sheets are seam welded at the four sides by means of electric resistance.Several extra seams are made longitudinally,Fig.12. The panel is then blown out from the inside by means of internal pressure through the performed inlet hole and piping.

4.2 <u>Joining the Riser Tubes with the Headers</u>

The headers are made of copper tubes 25.4 mm diameter and 1 mm wall thickness.The most suitable joining method of the riser tubes with the headers is brazing.Two fluxless brazing

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silver alloys were chosen for this purpose. They contain 2 - 15°/o Ag + 5 - 6.2°/o P + rest copper. The brazing temperature ranges between 650° - 810°C. T - drilled collars are formed in the equally spaced holes in the headers in order to secure a reasonably strong brazing area. The T - drill tool is lacally developed.
For plastic tubing Araldite and some other types of Epoxy adhesives were used for sealing the joints between risers and headers.

4.3 Absorber Coating

Black chrome mat paint is used for painting all absorber in order to increase absorbtivity and minimize reflectivity of the incident sun rays

4.4 Back Plates

Aluminium plates 1 mm thick are used as back plates.

4.5 Insulation

Steropore is used as insulation material between the absorber panel and back plate.

4.6 Collector Frame

Due to the superior light weight and high corrosion resistance, extruded anodized aluminium sections locally produced are selected for the fabrication of the collector frame.

4.7 Glazing

The following glazing materials are used and investigated in combination with the different collectors.
a) Ordinary glass plates egyptian made 6 mm thick
b) Ordinary etched glass plates egyptian made 6 mm thick
c) Fiberglass reinforced polyester egyptian made 2 mm thick
d) Teflon and Tedler foils imported from U.S.A.

4.8 Sealing the Collector

A silicone base sealing paste is used for sealing the glass cover attachment to the frame against leakage of dust, wind and humidity. It withstands high and low temperature, cyclic changes and thermal expansion and contraction as well.

5. Testing of the Collectors

A test stand is build to test thermal performance of the developed collectors. The stand includes several parallel systems (tanks, piping, measuring equipment etc.).
The thermal performance of these systems are to be tested following the standard procedure of the American Bureau of Standards (NBS) and the German Bundesverband für Solarenergie (BSE). The test rig is equiped with a complete microprocessor based data aquisition system in order to monitor the

time dependent performance of the collectors.It includes the temperatures,flow and insolation measurements as well as wind speed Azimuth angle etc.

Conclusion

16 different novel collectors were designed and manufactured. All materials used in these collectors are either from local market or self developed except the brazing alloys and the selective paints.Simple local fabricating thechniques are used in the production of these collectors.