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Comparative Study of Different Types of Solar Collectors Suitable for Vapour Absorption Refrigeration System

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Abstract— In this paper a survey of the various types of solar thermal collectors and applications for Refrigeration system is presented. A introduction into the uses of solar energy is attempted followed by a description of the various types of collectors including flat-plate, parabolic dish, evacuated tube, parabolic trough, Fresnel lens,. Typical applications of the various types of collectors are presented. These include solar water heating which comprise refrigeration applications

Keywords—Solar collectors; Water heating; Cooling; vapour refrigeration system

1. INTRODUCTION

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector [2]. The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment, or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days.

2. SOLAR COLLECTORS

A large number of solar collectors are available in the market. There are basically two types of solar collectors: non concentrating or stationary and concentrating. A non concentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux.Types of Collectors are

2.1 Flat plate collectors (FPC)

FPC have been built in a wide variety of designs and from many different materials. They have been used to heat fluids such as water, water plus antifreeze additive, or air. Their major purpose is to collect as much solar energy as possible at the lower possible total cost. The collector should also have a long

effective life, despite the adverse effects of the sun's ultraviolet radiation, corrosion and clogging because of acidity, alkalinity or hardness of the heat transfer fluid, freezing of water, or deposition of dust or moisture on the glazing, and breakage of the glazing because of thermal expansion, hail, vandalism or other causes. These causes can be minimised by the use of tempered glass [8]. The characteristics of a typical water FPC are shown in table 1

Table 1 : Characteristics of a typical water FPC

Parameter	Flate Plate Collector
Fixing of risers on the absorber plate	Embedded
Absorber coating	Black mat paint
Glazing	Low iron glass
collector slopeangle	Latitude +5 to 10^o
Flow rate per unit area at test conditions	0.015
Intercept effeciency	0.79

2.2 Parabolic Disc collectors (PDC)

The selection of type of energy source depends on economic, environmental and safety considerations [12]. Solar energy is considered to be more suitable on the basis of environmental and safety considerations. Solar thermal systems are one of the main technologies for solar energy utilisation. It can be used for generation of thermal energy such as air heating, hot water generation and in drying application. Solar collector is one of the main components in a solar thermal system [16]. It absorbs the solar radiation as heat and transfers it to the heat transport fluid. Based on the way of solar collection, the solar collectors are classified into non concentrated and concentrated type. A non-concentrated solar collector has the same area for intercepting and absorbing solar radiation, while concentrated type will have a concave shaped reflective surface for intercepting radiation and it will be focused to a small area and thus increases radiation flux. Another advantage of concentrated collectors is that higher temperature can be achieved than that of non- concentrated collectors.

PDC are non-imaging concentrators. These have the capability of reflecting to the absorber all of the incident radiation within wide limits. The necessity of moving the concentrator to accommodate the changing solar orientation can be reduced by using a trough with two sections of a parabola facing each other. Compound parabolic concentrators can accept incoming radiation over a relatively wide range of angles.

A parabolic dish collector is a type point focusing concentrating collector. The incoming beam radiations falling on the surface parallel to the axis of the dish concentrated at the focal point of the dish. This system uses a dual axis tracking which clearly means that it had to follow sun throughout the day in order for high efficiency. This system can attain temperature as high as 1500^0C. A parabolic dish is shown in figure

Parabolic dishes have several important advantages. They are always pointing the sun, they are the most efficient of all collector systems. They have modular collector and receiver units that can either function independently or as part of a larger system of dishes. They typically have concentration ratio in the range of 600–2000, and thus are highly efficient at thermal-energy absorption and power conversion systems..

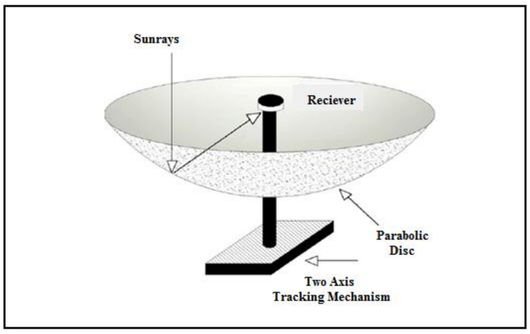

Fig 1 : Parabolic Disc Type Solar Collector

Dishes track the sun on two axes, and thus they are the most efficient collector systems because they are always focussed. Concentration ratios usually range from 600 to 2000, and they can achieve temperatures in excess of 1500 ^{o}C.

Table 2 : Characteristics of a typical PDC

Parameter	Value
F' : collector fin efficiency factor	0.9
U_L : overall loss coefficient of collector per unit aperture area (W/m^2 °C)	1.5
ρ_R : reflectivity of walls of CPC	0.85
θ_c : half-acceptance angle of CPC (degrees)	45
Ratio of truncated to full height of CPC	0.67
Axis orientation	Receiver axis is horizontal and in a plane with a slope of 35° (transverse)
a: absorbtance of absorber plate	0.95
N_G : number of cover plates	1
η_R : index of refraction of cover material	1.526
K_L : product of extinction coefficient and the thickness of each cover plate	0.0375
Collector slope angle	(local latitude)

2.3 Evacuated tube collectors (ETC)

ETC have demonstrated that the combination of a selective surface and an effective convection suppressor can result in good performance at high temperatures .The vacuum envelope reduces convection and conduction losses, so the collectors can operate at higher temperatures. However, their efficiency is higher at low incidence angles. ETC use liquid–vapour phase change materials to transfer heat at high efficiency. Evacuated tube collectors are composed of multiple evacuated glass tubes. Conventional simple flat-plate solar collectors were developed for use in sunny and warm climates. Their benefits however are greatly reduced when conditions become unfavourable during cold, cloudy and windy days. Furthermore, weathering influences such as condensation and moisture will cause early deterioration of internal materials resulting in reduced performance and system failure. Evacuated heat pipe solar collectors (tubes) operate differently than the other collectors available on the market. These solar collectors consist of a heat pipe inside a vacuum-sealed tube, as shown in Fig 2. ETC use liquid–vapour phase change materials to transfer heat at high efficiency. These collectors feature a heat pipe (a highly efficient thermal conductor) placed inside a vacuum-sealed tube. Because no evaporation or condensation above the phase-change temperature is possible, the heat pipe offers inherent protection from freezing and overheating. This self limiting temperature control is a unique feature of the evacuated heat pipe collector [14].

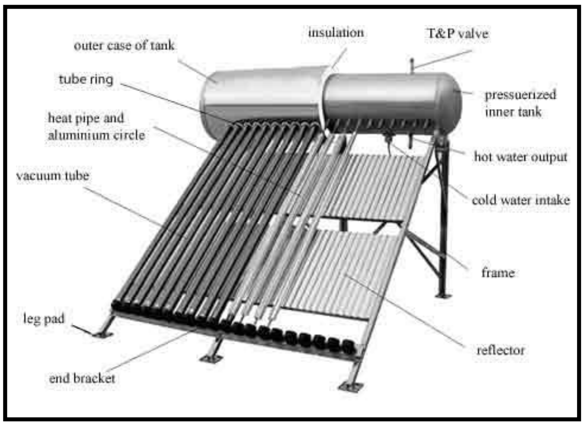

Fig 2 : Evacuated Tube Solar Collector

Another type of collector developed recently is the is an ETC in which at the bottom part of the glass tube a reflective material is fixed [16]. The collector combines the vacuum insulation and non-imaging stationary concentration into a single unit. In another design a tracking ICPC is developed which is suitable for high temperature applications.ETC have demonstrated that the combination of a selective surface and an effective convection suppressor can result in good performance at high temperatures.The vacuum envelope reduces convection and conduction losses, so the collectors can operate at higher temperatures than FPC [12]. Like FPC, they collect both direct and diffuse radiation. However, their efficiency is higher at low incidence angles. This effect tends to give ETC an advantage over FPC in day-long performance.

Table 3: Characteristics of a ETC

Parameter	Value
Glass tube diameter	65 mm
Glass thickness	1.6 mm
Collector length	1965 mm
Absorber plate	Copper
Coating	Selective
Absorber area for each collector	0.1 m^2
Efficiency mode	$mv_s(T_i - T_a)/G$
G_{test} : flow rate per unit area at test conditions (kg/s m^2)	0.014
c_0 : intercept efficiency	0.82
c_1 : negative of the first-order coefficient of the efficiency (W/m^2 °C)	2.19
b_0 : incidence angle modifier constant	0.2
Collector slope angle	Latitude +5 to 10°

2.4 Parabolic trough collectors (PTC)

In order to deliver high temperatures with good efficiency a high performance solar collector is required. Systems with light structures and low cost technology for process heat applications up to 400 °C could be obtained with parabolic through collectors (PTCs). PTCs can effectively produce heat at temperatures between 50 and 400 °C. Parabolic trough technology is the most advanced of the solar thermal technologies because of considerable experience with the systems and the development of a small commercial industry to produce and market these systems. PTCs are built in modules that are supported from the ground by simple pedestals at either end.

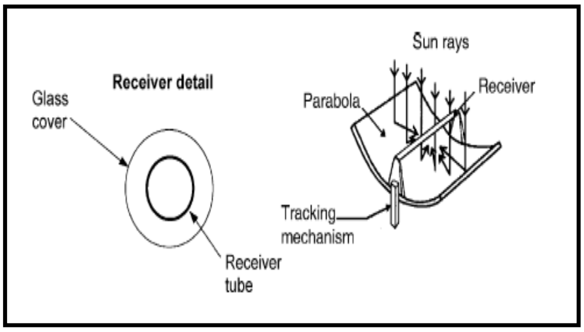

Fig 3 : Parabolic Trough Collector

A tracking mechanism must be integrated compound parabolic collector (ICPC). This reliable and able to follow the sun with a certain degree of accuracy, return the collector to its original position at the end of the day or during the night, and also track during periods of intermittent cloud cover. Additionally, tracking mechanisms are used for the protection of collectors, i.e. they turn the collector out of focus to protect it from the hazardous environmental and working conditions, like wind gust, overheating and failure of the thermal fluid flow mechanism.

After a period of research and commercial development of the PTC in the 80s a number of companies entered into the field producing this type of collectors, for the temperature range between 50 and 300 ^oC, all of them with one-axis tracking. One such example is the solar collector produced by the Industrial Solar Technology (IST) Corporation. Characteristics of the IST Collector is shown in table 4.

2.2 Linear Fresnel Reflector (LFR)

The LFR field can be imagined as a broken-up parabolic trough reflector, but unlike parabolic troughs, it does not have to be of parabolic shape, large absorbers can be constructed and the absorber does not have to move. A representation of an element of an LFR collector field. The greatest advantage of this type of system is that it uses flat or elastically curved reflectors which are cheaper compared to parabolic glass reflectors. Additionally, these are mounted close to the ground, thus minimizing structural requirements.

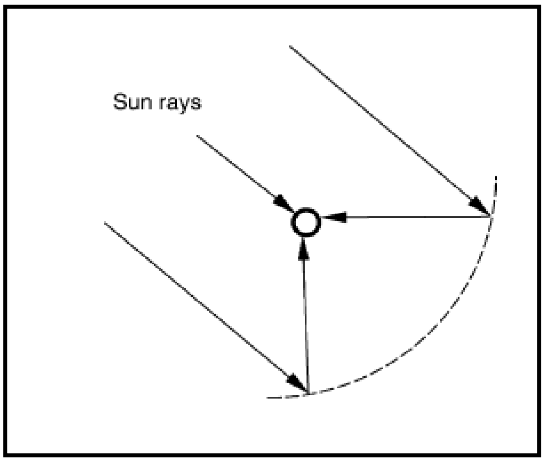

Fig 4 : Fresnel type parabolic trough collector.

Table 4 : Characteristics of the IST Collector system

Parameter	Value/type
Collector rim angle	70°
Reflective surface	Silvered acrylic
Receiver material	Steel
Collector aperture	2.3 m
Receiver surface treatment	Highly selective blackened nickel
Absorptance	0.97
Emittance (80 °C)	0.18
Glass envelope transmittance	0.96
Absorber outside diameter	50.8 mm
G_{test} : flow rate per unit area at test conditions (kg/s m^2)	0.015
k_o : intercept efficiency	0.762
k_1 : negative of the first-order coefficient of the efficiency (W/m^2 °C)	0.2125
k_2 : negative of the second-order coefficient of the efficiency (W/m^2 °C^2)	0.001672
b_0 : incidence angle modifier constant	0.958
b_1 : incidence angle modifier constant	−0.298
Tracking mechanism accuracy	0.05°
Collector orientation	Axis in N–S direction
Mode of tracking	E–W horizontal

3. SOLAR REFRIGERATION

Solar cooling can be considered for two related processes: to provide refrigeration for food and medicine preservation and to provide comfort cooling. Solar refrigeration systems usually operate at intermitted cycles and produce much lower temperatures (ice) than in air conditioning. When the same cycles are used in space cooling they operate on continuous cycles. The cycles employed for solar refrigeration are the absorption and adsorption. During the cooling portion of the cycles, the refrigerant is evaporated and reabsorbed. In these systems the absorber and generator are separate vessels [10]. The generator can be integral part of the collector, with refrigerant absorbent solution in the tubes of the collector circulated by a combination of a thermosyphon and a vapour lift pump.

The single effect absorption chiller is mainly used for building cooling loads, where chilled water is required at 6–7 ^oC. The double effect absorption chiller has two stages of generation to separate the refrigerant from the absorbent [16]. Thus the temperature of the heat source needed to drive the high-stage generator is essentially higher than that needed for the single-effect machine and is in the range of 155–205 ^oC.There are many options available which enable the integration of solar energy into the process of 'cold'
production. Solar refrigeration can be accomplished by using either a thermal energy source supplied from a solar collector [11]. This can be achieved by using thermal absorption units or conventional refrigeration equipment. Solar refrigeration is employed mainly to cool vaccine stores in areas with no mains electricity

and for solar space cooling. Water–ammonia has been the most widely used sorption–refrigeration pair and research has been undertaken to utilise the pair for solar-operated refrigerators. The efficiency of such systems is limited by the condensing temperature, which cannot be lowered without introduction of advanced and expensive technology.

The performance of vapor absorption refrigeration system depends upon the generator temperature which can be increased by using a proper system of solar collectors.

4. RESULTS AND DISCUSSION

In the study of solar collectors for refrigeration system it is shown that different collectors can be utilized for different temperature ranges for refrigeration cycles either using single effect, double effect triple effect cycles. Flat plate collectors were used for single effect cycle and evacuated tube collectors were used for double effect cycle. As a result of this study it may be proposed to use a combination of evacuated tube collector and parabolic collector connected in series to form a conjugate system of collector for better performance as by using separate flate plate, evacuated tube of parabolic disc collectors. The conjugate collector system may perform better and give much better performance results for vapor absorption system working in a single effect refrigeration cycle.

5. CONCLUSION

Several of the most common types of solar collectors are presented in this paper. The various types of collectors described include flat-plate, parabolic disc, evacuated tube, parabolic trough, and Fresnel lens, The characteristics of solar collectors are also presented. Additionally, several applications are also described in order to show the extent of their applicability. These include water heating, cooling, refrigeration etc. It should be noted that the applications of solar energy collectors for refrigeration is not limited. There are many other applications which are not described here either because they are not fully developed or are not matured yet. The collectors described in this paper show that their application for refrigeration can be used in a wide variety of systems, could provide significant environmental and financial benefits, and should be used whenever possible.

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