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SOLAR POWER TECHNOLOGIES, REFRIGERATION AND COOLING SYSTEMS – REVIEW

Mohsin J. Dadi[#1], Arjun K. Vyas[#2], and Dhaval R. Sodha[#3]

[#]*Department of Mechanical Engineering, Faculty of Engineering & Technology,*
Parul University, Waghodia, Vadodara, India

Abstract— Energy is the heart of the modern world. This paper provides a detailed review of solar photovoltaic and concentrated solar power technologies. The status of solar photovoltaic technology being commercially developed, subsidized and mature technology is suited for both residential and commercial applications. On the other side, concentrated solar power technology despite having higher capital cost yield higher economic returns hence suited for commercial applications.

This paper also provides a review of different solar refrigeration technology and cooling methods. Different cooling systems using various working fluids assisted by solar energy are reviewed. Solar powered refrigeration technologies are classified into four categories: Solar photovoltaic cooling systems, solar thermo-electrical cooling, solar thermo-mechanical cooling and solar thermal cooling techniques which includes sorption, absorption and adsorption systems. In this article we have tried to produce a review based on solar energy collection and coefficient of performance of different refrigeration systems.

Keywords— Renewable energy, PV system, Concentrated solar power (CSP), Absorption, Adsorption

I. INTRODUCTION

Energy security is the ability of a nation to deliver the energy resources needed to ensure its development and implies secure supply and stable prices. Energy is playing vital for developing and welfare of a nation’s economy. The economic growth and technological advancement of every developing country depends on energy [1] and the amount of available energy reflects that country’s quality of life. To minimize the harming environmental problems of global warming, now a day’s scientists and engineers are focusing on research worldwide to protect ozone layer worldwide. Main source of harming global warming are burning fossil fuesl, gases, CFCs etc. As results of the rapid growth in world population and the economy total world energy consumption is projected to increase by 71% from 2003 to 2030 [2].

Diversification of sources and policies to control energy consumption are two main objectives of European strategy to decrease the energy dependency. The key to diversification is renewable energy sources (RES), because they have significant potential to contribute to a sustainable development [3].

II. RENEWABLE ENERGY

Energy that is produced from natural resources is term as “renewable energy” which is having inexhaustibility over time and natural renewability. It is also known as non-conventional sources which include Solar Energy, Hydro Power, Biomass, Wind, geothermal [4].

Developing countries had implemented various renewable energy technologies by putting numerous efforts. Renewable energy is cost effective and non-polluting compared to fossil fuels. Solar energy stands out on the list of renewable energy sources due to environmentally friendly and naturally available sources among all renewable resources [5].

Solar Energy

Solar energy had paid more attention by researchers and scientists due to global energy shortage [6]. Solar Power is using for water heating, cooking, power generation, refrigeration nowadays [1].

Sun is producing electromagnetic radiation due to thermo nuclear reactions, called as solar energy. Solar energy is visible, ultraviolet and infrared. Excluding nuclear, tidal and geothermal all renewable energy sources on earth are directly or indirectly depending on sun. The sun actually transmits vast amount of solar energy to the surface of the earth [7]. Influx of solar energy radiation is termed as Solar Constant, S. Choudhury et al. [8] calculated a mean solar constant value equal to1368 W/m^2. Therefore, considering a global plane area of 1.275 × 1014 m^2 and the mean radius of the earth being approximately 6371 km, the total radiation transmitted to the earth is 1.74 × 1017 W [9].

Solar power plant in Sweden is working since 2001 due to its cleanliness, pollution free, low maintenance cost and natural availability. In Iran solar heated water plant in the rural areas are introduced by Turanjanin [10]. They concluded that from May to September maximum radiation are observed. Now a days developing countries are facing problems with refrigeration systems as both commercial and residential uses are increased rapidly during summer season. [11]. It is not possible to accommodate high energy consumption system such as cooling and refrigeration due to limited resources of electrical energy and storage in developing countries. Therefore, solar refrigeration technologies have become a worldwide focal point; this energy crisis has opened the door for solar energy to handle not only peak electricity demands but also cooling issues.

The potential of solar energy makes it beneficial, in a variety of ways such as:

- The areas in tropical and sub-tropical regions receive a higher amount of solar radiations throughout the whole year thus countries in these regions have a significant potential to harness solar energy for their electricity requirements.
- Most of the fossil fuels and energy resources lead towards the climate change and consequently, a social decline. Thus, solar energy in comparison to fossil fuel is a sustainable source of clean energy. Solar power is environmentally friendly, and its social acceptance has been significantly increased due to its reliability and efficient performance.
- Solar power systems are relatively affordable, and they are suitable for both urban and rural areas.

III. CONCENTRATED SOLAR POWER (CSP)

Concentrated solar power (CSP) or solar thermal systems use mirrors and lenses to concentrate a large area of naturally available solar energy, on to a small area. The concentrated beam of light can be used to generate the electric power once it is converted into heat through an efficient utilization of thermodynamic cycle [12].

The major advantage of CSP systems over other solar power technologies is their capability to provide electricity even in the absence of sun. The main characteristics of solar power plants utilizing CSP technology areas follow [13]: High efficiencies can be achieved because CSP technology utilizes thermodynamic cycle with high temperature input.

- Solar radiations are directly used in CSP technology. It implies losses of the diffused radiation and reflection.
- Higher values of Direct Normal Irradiation (DNI) are requires in CSP technology.
- Due to high capital cost, CSP technology is not suitable for small scale solar power plants.

The growth of CSP technology is expected to increase at a fast pace. According to Sawin and Martinot [14], parabolic trough collectors are installed 90% in CSP power plants globally over existing CSP technologies.

Concentration Technologies of CSP

Concentration technologies of CSP systems usually exist in four forms containing parabolic trough, Linear Fresnel collector, parabolic dish and solar power tower. Different types of light concentrators produce varying amounts of peak temperatures representing variant thermodynamic efficiencies depending on the ways of tracking the sun and focusing insolation.

New innovations and improvements in technology have made CSP systems more efficient and cost effective [15]. Different light concentration techniques have certain advantages over flat-plate, conventional type CSP systems. Fig. 1 shows the different CSP concentration technologies while Table-1 presents an overview and comparison of CSP technologies. The main advantages are listed below:

- As compared to the flat-plate solar energy collecting surface, the working fluid can achieve higher peak temperatures in a light concentrating system.
- The thermal efficiency of the light concentrating system is higher because of the small heat loss area in relation to the receiver area.

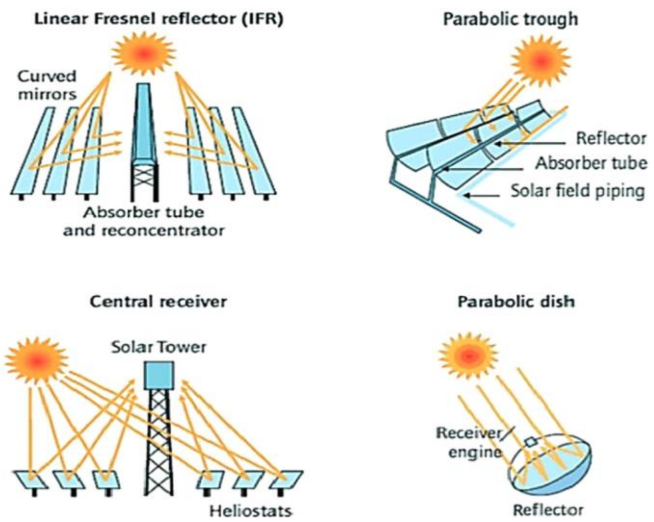

Fig 1. Four main CSP technologies, Source International Energy Agency (IEA)

TABLE I
OVERVIEW AND COMPARISON OF CSP TECHNOLOGIES.[15-18]

	Parabolic troughs	**Linear Fresnel reflectors**	**Solar towers**	**Solar towers Parabolic dish (Dish-Stirling)**
How it works?	By focusing the parabolic sheet to a fixed point where objects intended to be heated are placed, It can be single axis or dual axis(for tracking of the sun)	The Long and thin segment of mirrors are used to focus incoming rays to the fixed absorber then concentrated heat goes to a heat exchanger to drive steam generator	The larger number of heliostats are used for focusing sun rays on to a central receiver then the heated fluid such as molten salt is used to produce steam for electricity generation	It uses mirrored dishes to concentrate sunlight onto a central receiver and then the converted thermal energy can be used to produce electricity, or it can also be routed to the main grid
Capacity (in MW)	10–300	10–200	10–200	0.01–0.025
Commercially mature or not?	It has been commercially proven	Pilot projects	Pilot commercial projects	Demonstration projects
Solar-to-electricity efficiency in% (Annual)	11–16	13	7-20	12-25
Temperatures (in °C)	350–550	390	250–565	550–750
Storage systems exist?	YES	YES	YES	NO
Advantages	Most mature CSP technology. It can produce heat at higher temperatures	More concentration of sunlight Cheaper than parabolic trough collectors	Increased efficiency. They can generate electricity in the absence of the sun. Economically proven	Higher efficiencies. The most efficient systems.
Disadvantages	Use of oil-based heat transfer media restricts output to moderate steam	Less efficient. Difficult to integrate storage capacity into their design	Requires a large area of land. Daily maintenance.	High cost. Lack of flexibility. Heat transfer requires a large number of equipment's.

IV. PHOTOVOLTAIC (PV) TECHNOLOGY

Photovoltaic (PV) technology directly converts incident solar energy into electrical energy, according to the principle of photoelectric effect. It uses diffused components of incoming solar radiations; hence PV technology is suitable for areas having low as well as high direct irradiance. Power generation employing PV technology makes use of solar panels, which are composed of different kinds of photovoltaic materials. Some of the most commonly used materials include mono and poly- crystalline silicon, Cadmium telluride (CdTe), Gallium arsenide (GaAs) as well as triple-junction solar cells composed of Indium gallium phosphide (InGaP).

A solar cell is generally a small electricity generation device. In order to generate electricity at a larger scale, solar cells are combined to form a module of multiple cells; these modules are then assembled into a (photovoltaic) PV array containing the length up to several meters. According to NREL [19], hundreds of solar arrays are interconnected to form a large system for utility-scale solar electricity generation.

Solar PV technology is sustainable, especially at the small scale [20]. PV systems can be either grid-connected (to the existing power grid) or stand-alone (independent units). These are categorized according to their configurations as fixed PV systems (normally oriented to the south at north facing latitudes and vice versa) and PV tracking systems (which follow the sun path in the sky on single or double axis track). PV systems with sun tracking ability are much more efficient than fixed systems because they track and face the sun all the time and they can capture the increased amount of incoming solar radiations. Nevertheless, PV tracking systems require a greater amount of area as compared to fixed PV systems as well as a part of generated electricity is utilized to track the sun.

The first application of PV technology was to the power the man-made satellites in orbits as well as other spacecrafts, but nowadays majority of PV modules are being used for the purpose of grid connected or standalone solar power generation

[21]. PV technology is also being used in many areas such as buildings integrated PV applications, transportation, telecommunication, solar roadways and rural electrifications etc. to name a few.

Generations of Photovoltaic Technology

PV technology can be broadly divided into three generations i.e., 1st Generation PV, 2nd Generation PV and 3rd Generation PV. The overall efficiency and performance of these PV generations vary greatly due to different types of semi-conductor materials used in them. 1st and 2nd Generation PV being more commercially mature yield large scale production while 3rd generation is in premature and R&D phase. Fig. 2 shows different types of PV systems.

According to Fraunhofer ISE [22], Si-wafer based technology had a share of about 90% of the total production in 2013 and the share of multi crystalline PV technology was about 55% of the total production. It has also been emphasized by Fraunhofer ISE [22] and Energy Informative [23], that the among the thin-film technologies CdTe leads with an annual production of 2GWp and currently has the largest market share. Amorphous-Si although a commercially mature technology is now being used for small scale applications only.CPV systems have gained much popularity and yield higher efficiencies.

Fig 1. From left to right: different types of PV systems. Source: NREL.[19]

V. SOLAR REFRIGERATION TECHNOLOGY

Solar refrigeration offers a wide variety of cooling techniques powered by solar collector-based thermally driven cycles and photovoltaic (PV)-based electrical cooling systems. Fig. 3 shows a schematic diagram of a solar thermal cooling system.

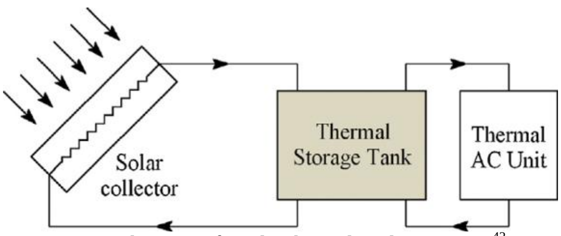

Fig 3. Schematic of a solar thermal cooling system.[42]

The solar collection and storage system consist of a solar collector (SC) connected through pipes to the heat storage. Solar collectors transform solar radiation into heat and transfer that heat to the heat transfer fluid in the collector. The fluid is then stored in a thermal storage tank (ST) to be subsequently utilized for various applications. The thermal AC (air-conditioning) unit is run by the hot refrigerant coming from the storage tank, and the refrigerant circulates through the entire system. Thermal storage is required as solar energy is time dependent. Solar cooling systems with thermal storage are shown in Table 2 [24]. Solar cooling is promising for energy savings with respect to traditional driven cooling system, advantage like conservation of energy and preserving the environment using solar cooling can be achieved. In solar refrigeration system solar energy is used by four methods as Solar PV cooling, Solar thermo electrical cooling, solar thermo mechanical cooling and solar thermal cooling for cooling purposes.

The first is a PV-based solar energy system; where solar energy is converted into electrical energy and used for refrigeration much like conventional methods [25]. The second one produce cool by thermoelectric processes [26, 27]. The third one produced mechanical energy from thermal energy, further on thermal energy is utilizing to produce refrigerating effect. The fourth method, refrigerant or working fluid directly heated by solar collectors using solar energy and utilizes heated refrigerant or working fluid to drive solar thermal refrigeration system. [7].

The performance of refrigeration systems is determined based on energy indicators of these systems. The COP (coefficient of performance) can be calculated as follows:

$$C = \frac{Eu}{Ec} \qquad (1)$$

Where Eu is the cooling usable energy; Ec is the consumed energy by system.

Equation to define energy efficiency ratio (EES), in British thermal unit per Watt-hours (Btu/ Wh) is:

$$EER = 3.143\ COP \quad (2)$$

Where 3.413 is the transformation factor from Watt to Btu/h.
Discussion on various solar refrigeration systems are follows.

TABLE 2
STAGES AND OPTIONS IN SOLAR COOLING TECHNIQUES[24]

Source	Source Conversion	Thermal storage (hot energy)	Production of cool energy	Thermal storage (cool energy)	Applications
Sun	Solar PV (electrical)	NA	1. Vapor compression Thermoelectric		1. Air conditioning (a) Office (b) Building (c) Hotel (d) Laboratory 2. Process industries (a) Dairy (b) Pharmaceutical (c) Chemical 3. Food preservation (a) Vegetables (b) Fruits (c) Meat and fish
	Solar thermal 1. Flat plate collector 2. Evacuated tube collector 3. Concentrated collector	1. Sensible 2. Latent 3. Thermo-chemical	1. Ejector 2. Desiccant 3. Absorption (a) Single effect (b) Half-effect (c) Double effect (d) Triple effect 4. Adsorption	1. Sensible 2. Latent 3. Thermo-chemical	

Solar Photovoltaic Cooling Systems

Solar energy can be converts into electrical energy by using solid state semiconductor called as photo voltaic cell. Due to huge and rapid demand of electrical energy in developing countries in the world, production of electricity by using photovoltaic cells are increasing over the past two decades. Fig. 4 shows global electricity production by PV Solar systems in different countries [28].

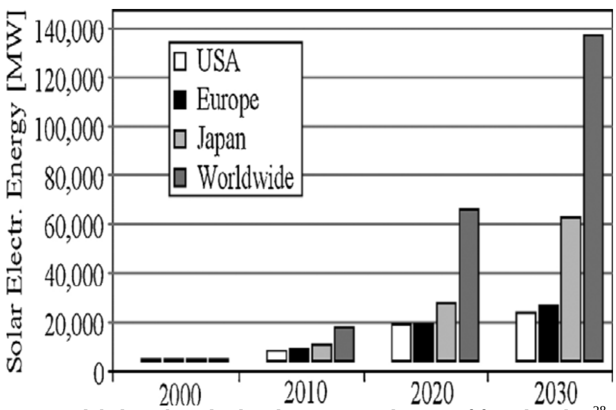

Fig 2. Global PV-based solar electricity production of four decades.[28]

Electricity produced from PV cells are DC electrical power while most of the application are using AC electrical power. To overcome this problem PV cooling systems are having four main components named as: photovoltaic modules, a battery, an inverter circuit and a vapor compression air conditioning system [29].

- Electricity can be produced by converting solar energy into DC electrical energy using Photo voltaic cell.
- Electrical energy as a DC power can be stored by using battery in day time and utilize stored electrical energy while solar energy is not available.
- DC electrical power can be converted in AC power by using inverter.
- AC electrical power can be utilized to run air conditioning system by using vapor compression refrigeration system.

The PV system can perform as a standalone system (Fig. 5), a hybrid system (working with an oil/hydro/gas power plant) or as a grid or utility intertie systems. Though the efficiency of PV module scan be increased by using inverters, their COP and efficiency are still not desirable.

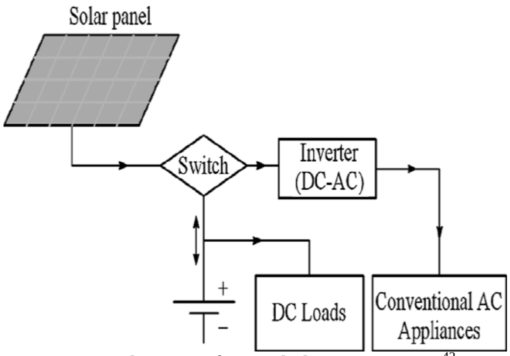

Fig 3. Schematic of a stand-alone PV system.[42]

Solar Thermo-Electrical Cooling

In solar electric cooling, power produced by the solar PV devices is supplied either to the Peltier cooling systems. It is possible to produce cool by thermoelectric processes, using the principle of producing electricity from solar energy through thermo electric effect and the principle of producing cool by Peltier effect. It has been produced such thermoelectric refrigerators as shown in Fig. 6.

Thermoelectric generator consists of a small number of thermocouples that produce a low thermoelectric power, but which can easily produce a high electric current. It has the advantage that can operate with a low-level heat source and is therefore useful to convert solar energy into electricity. The thermoelectric refrigerator is also composed of a small number of thermocouples through which run the current produced by the generator. The combination of the two parts is compatible with use as thermoelectric materials of the semiconductors based on Bi_2Te_3 [30].

Vella et al, [26] showed that a thermoelectric generator, which draws its heat from solar energy, is a particularly suitable source of electrical power for the operation of a thermoelectric refrigerator. They developed the theory of the combined thermoelectric generator and refrigerator and determined the ratio of the numbers of thermocouples needed for the two devices. A 4-couple thermoelectric generator has been used to power a single-couple refrigerator. Less than 0 °C temperature have been achieved across the generator by maintaining temperature difference around.

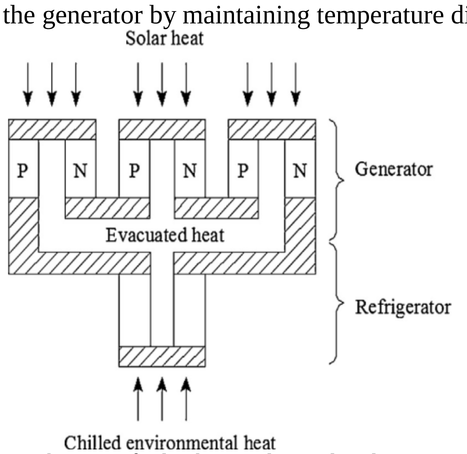

Fig 4. Schematic of solar thermo-electrical cooling system.[42]

Solar Thermo Mechanical Cooling

Mechanical energy can be obtained from thermal energy by using the thermo mechanical solar cooling system. Further on refrigeration effect can be produce by utilizing mechanical energy.

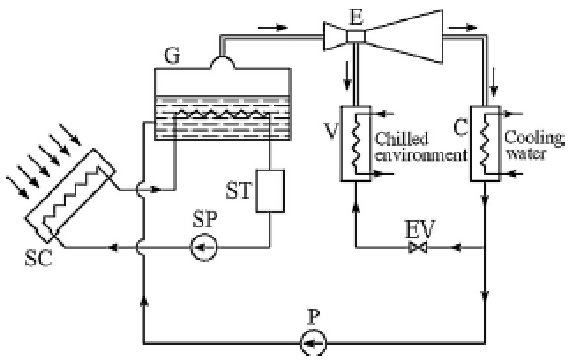

Fig 5. Schematic of steam jet solar cooling system.[42]

The steam ejector system represents the thermo-mechanical cooling technology. Fig. 7 illustrates the steam ejector system integrated with a parabolic solar collector SC. The steam produced by the solar collector is passing through the steam jet ejector E. During this process, the evaporator pressure is reduced, and water is vaporized in the evaporator V by absorbing the heat from the coldwater.

When cooling is not needed, the steam turbines can be used to produce electricity. Most of the steam ejector system require steam at pressures in the range of 0.1–1.0 MPa, and temperatures in the range of 120–180℃ [31]. However, Loehrke [32] proposed and demonstrated that the steam ejector system could be operated using low-temperature solar heat by reducing the operating pressure under atmospheric pressure. Khattab and Barakat [33] later proved this concept by developing a detailed mathematical model of the solar steam ejector cycles operating at low pressure and low temperature for the air-conditioning application.

The working fluid used in a solar ejector cooling system lead to different performance depending on operating conditions. In order to compare the performance of different used working fluids, in Table 3 are presented the following values: t_g – the generating temperature; t_c – the condensation temperature achieved in condenser C (37 ℃ for cooling with cooling tower, 30℃ for cooling with cold water); p_g – the pressure in the generator G (maximum pressure in the system); p_e – the pressure in the evaporator V (minimum pressure in the system); COP – the theoretical coefficient of performance; η_{ej}– the ejector efficiency; $COP_r = COP – \eta_{ej}$, the real coefficient of performance; Q_{SC}– the heat needed to be supplied by solar collector in generator to achieve a cooling power of 1.16×10^4 W; A_{SC}– the solar collector area, assuming a solar flux of 0.8 kW/m^2 and capture efficiency of 0.5, for achieving a cooling capacity of 1.16×10^4 W. Considering one flat-plate collector, the possible temperature for which can easily provide solar heat is t_g = 85 ^{0} C, and for a parabolic-cylinder concentrating collector can be adopted t_g= 130 ^{0} C.

TABLE 3
PERFORMANCES OF DIFFERENT WORKING FLUIDS USED IN SOLAR STEAM EJECTOR SYSTEMS.[42]

Working Fluid	$t_{g\,(°C)}$	$t_{c\,(°C)}$	p_g (KPa)	P_e (KPa)	COP	η_{ef}	COP_r	Q_{SC} (W)	A_{SC} (m^2)
H_2O	85	37	392.2	0.88	0.913	0.184	0.168	69,130	173
		30	392.2	0.88	1.471	0.217	0.319	36,396	91
	130	37	475.5	0.88	2.076	0.226	0.469	24,717	62
		30	475.5	0.88	2.887	0.223	0.645	17,979	45
R-11	85	37	460.8	50	0.936	0.196	0.183	63,428	159
		30	460.8	50.1	1.947	0.226	0.440	26,356	66
	130	37	784.0	50.1	1.708	0.226	0.386	26,911	67
		30	784.0	50.1	3.121	0.216	0.675	17,175	43
R-21	85	37	754.9	90.2	0.790	0.172	0.135	85,630	215
		30	754.9	90.2	1.162	0.209	0.242	47,866	120
Propane	85	37	2745	539	0.496	0.078	0.039	298,969	750
		30	2745	539	1.038	0.198	0.209	56,585	142
Butane	85	37	882.3	147	0.423	0.091	0.038	302,475	758
		30	882.3	147	0.666	0.170	0.113	102,284	256
NH_3	85	37	2157	520	Not Possible Solution				
	130	37	2157	520	0.348	0.016	0.005	2,130,150	5338

Analyzing the COP_r values from this table results as the competitive working fluids: water and Freon, among which best is R-11. Water and R-11 have comparable COP_r, but operating pressures in the system are very different. Thus, for the use of flat plate collectors (t_g = 85 ^{0} C), steam ejector cooling system works completely in depression (p_e and p_g is less than atmospheric pressure). So if water is used as refrigerant leakage problems are to be solved to avoid air entering the system.

Nehad [34, 35] compared the theoretical performance of the ejector system working with R-717, R-11, R-12, R-113 and R-114.Then he chooses R-113 as a refrigerant for the experiment since it has a higher COP_r, a reasonable operating pressure, and is non-toxic. The ejector systems are mostly used in air conditioning applications, but they can be used in chemical and metallurgical industry for air cooling in areas with higher heat dissipation.

Solar Thermal Cooling Techniques

Solar thermal cooling (Fig. 3) is becoming more popular because a thermal solar collector directly converts light into heat. For example, Otanicar [29] described a thermal system that is capable of absorbing more than 95% of incident solar radiation, depending on the medium. Sorption technology is utilized in thermal cooling techniques. Due to physical and chemical changes between the refrigerant and sorbent, Cooling effect is achieved. Open sorption and closed sorption are two types of sorption system. [2].

Open Sorption Systems

Open system refers to solid or liquid desiccant systems that are used for either dehumidification or humidification. Basically, desiccant systems transfer moisture from one airstream to another by using two processes. In the sorption process the desiccant system transfer moisture from the air into a desiccant material by using the difference in the water vapor pressure of the humid air and the desiccant. If the desiccant material is dry and cold, then its surface vapor pressure is lower than that of the moist air, and moisture in the air is attracted and absorbed to the desiccant material. In desorption (regeneration) process, the captured moisture is released to the airstream by increasing the desiccant temperature. After regeneration, the desiccant material is cooled down by the cold air stream. Then it is ready to absorb the moisture again. When these processes are cycled, the desiccant system can transfer the moisture continuously by changing the desiccant surface vapor pressures, as illustrated in Fig. 8. To drive this cycle, thermal energy is needed during the desorption process. The difference between solid and liquid desiccants is their reaction to moisture.

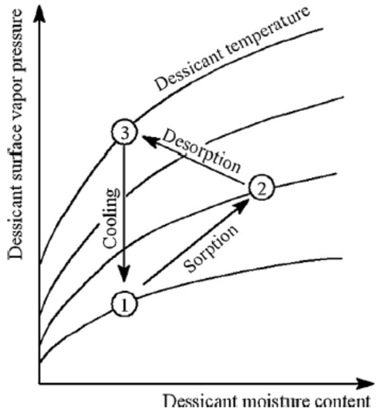

Fig 6 Process of moisture transfer by desiccant.[42]

Following are various open sorption systems.

a. Liquid desiccant system
b. Solid desiccant system
c. Desiccant solar cooling system.

Closed Sorption Systems

In closed sorption technology, there are two basic methods: absorption refrigeration and adsorption refrigeration.

Absorption Refrigeration

Absorption is the process in which a substance assimilates from one state into a different state. These two states create a strong attraction to make a strong solution or mixture. The absorption system is one of the oldest refrigeration technologies. The first evolution of an absorption system began in the 1700s. It was observed that in the presence of H_2SO_4 (sulphuric acid), ice can be made by evaporating pure H_2O within an evacuated container. In 1859, a French engineer named Ferdinand Carre designed an installation that used a working fluid pair of ammonia/water (NH_3/H_2O). In1950, a new system was introduced with a water/lithium bromide ($H_2O/LiBr$) pairing as working fluids for commercial purposes [36].

The absorption refrigeration technology consists of a generator, a pump and an absorber that are collectively capable of compressing the refrigerant vapor. The evaporator draws the vapor refrigerant by absorption into the absorber. The extra thermal energy separates the refrigerant vapor from the rich solution. The condenser condenses the refrigerant by rejecting the heat and then the cooled liquid refrigerant is expanded by the evaporator, and the cycle is completed. The refrigerant side of the absorption system essentially works under the same principle as the vapor compression system.

However, the mechanical compressor used in the vapor compression cycle is replaced by the thermal compressor in the absorption system. The thermal compressor consists of the absorber, the generator, the solution pump, and the expansion valve. The attractive feature of the absorption system is that any types of heat source, including solar heat and waste heat, can be utilized in the desorber. Typical refrigerant/absorbent pairs used in the absorption system are NH_3/H_2O and $H_2O/LiBr$. The thermodynamic characteristics of these have been described in various studies and experiments [37, 38]. Even though NH_3/H_2O and $H_2O/LiBr$ pairs have been used all over the world, researchers are still looking for new pairs [39]. Based on the thermodynamic cycle of operation and solution regeneration, the absorption systems can be divided into three categories: single-, half-, and multi-effect (double-effect and triple-effect) solar absorption cycles. The single-effect and half-effect chillers require relatively lower hot-water temperatures with respect to multi-effect systems [40]. Best absorption refrigeration technology applications are heat-activated refrigerators, gas-fired residential air conditioners, and large industrial refrigeration plants.

Adsorption Refrigeration

Adsorption technology was first used in refrigeration and heat pumps in the early 1990s. The adsorption process differs from the absorption process in that absorption is a volumetric phenomenon, whereas adsorption is a surface phenomenon. The primary component of an adsorption system is a solid porous surface with a large surface area and a large adsorptive capacity. Initially, this surface remains unsaturated. When a vapor molecule contacts the surface, an interaction occurs between the surface and molecules, and the molecules are adsorbed on to the surface [4].

In an adsorption refrigeration technique, the working pair plays a vital role for optimal performance of the system. Thus, there are some working pairs: silica gel/water; activated-carbon/methanol; activated-carbon/ammonia; zeolite/water; activated-carbon granular and fibre adsorbent, etc. The adsorption cycle is composed of two sorption chambers, an evaporator, and a condenser [2].

Water is vaporized under low pressure and low temperature in the evaporator. Then the water vapor enters the sorption chamber where the solid sorbent, such as silica gel, adsorbs the water vapor. In the other sorption chamber, the water

vapor is released by regenerating the solid sorbent by applying the heat. Then the water vapor is condensed to liquid by the cooling water supplied from a cooling tower. By alternating the opening of the butterfly valves and the direction of the cooling and heating waters, the functions of two sorption chambers are reversed. In this way, the chilling water is obtained continuously.
The adsorption cycle achieves a COP of 0.3–0.7, depending upon the driving heat temperature of 60–95 ^{0} C [41]. Adsorption refrigeration technology has been used for many specific applications, such as purification, separation and thermal refrigeration technologies.

VI. CONCLUSION

Solar Energy has been of considerable interest now a day because of promising advantages. As the population of world is increasing day by day and supply of conventional fuel is decreasing researchers are focusing on Renewable Energy. The cooling demand has been increased due to human comfort as well as recent climate change; cooling technologies based on solar Energy are promising technologies for upcoming years.
Solar refrigeration and cooling systems are more suitable than conventional system as refrigerants used are pollution free working fluids. Solar cooling system can be used to improve the indoor air quality of residential buildings, hotels, schools, colleges, offices and research laboratories.
In this paper, an extensive review of concentrated Solar Power and Photo Voltaic technology are presented. Along with CSP and PV technology, technologies related to the maximum utilization of solar energy for refrigeration and cooling purpose are presented. The working fluid used in solar ejector cooling has compared and by analyzing the COPr values it is found that R-11 is best. The adsorption cycle needs a lower heat source temperature than the absorption cycle.
Policy makers have to encourage and offer promotional schemes for the success of solar cooling systems in next few years. Manufacturers have to undertake efforts on cost efficiency as well as for developing better technology for solar cooling systems.

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