A review of solar energy storage techniques of solar air collector

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Abstract: - Many industrial applications of solar air collectors have led to study and summarize the recent papers relating to this topic. The high performance of the energy conversion and energy storage performance of the solar collectors has drawn the increasing attention energy research field. This review paper focuses to the developments and solar thermal applications, providing a review of thermal energy storage systems and solar collectors. Many types of solar collectors are presented and discussed, including both concentrating and non-concentrating solar collectors. The goal of this review is to provide the necessary information for further research in the development of cost effective high temperature thermal storage systems. Finally, presenting and future solar power stations are overview.

Key-Words: - solar collector; solar applications; photovoltaic; concentrating collectors**.**

1 Introduction

Solar air heaters are simple devices that utilize incident solar radiation to obtain clean energy for a wide usage. The solar air heater device intercepts solar radiation, converts this radiation to the heat in air and delivers the air for use. The main components of a solar air heater is an absorber plate, one or more channels for the flowing air, insulation for the bottom and lateral sides of the solar collector and one or more transparent covers. The use of a blower is optional for the air supply. Thermal performance of solar air heaters is approximately poor from solar water heaters. The increasing convective of heat transfer coefficient due to increase Thermal performance. There are two ways for increasing heat transfer coefficient either increase the area of absorbing surface by using fins or create the turbulence on the heat transferring surfaces.

Thermo hydraulic performance of a solar air heater may be improved by providing artificial roughness on the absorber plate. The artificial roughness has been used extensively for the enhancement of forced convective heat transfer, which further requires flow at the heat-transferring surface to be turbulent. However, energy for creating such turbulence comes from the fan or blower and the excessive power is required to flow air through the duct. Therefore, it is better that the turbulence must be created only in the region very close to the heat transferring surface, so that the power requirement may be lessened. The height of the roughness elements can be kept to be a small in comparison with the duct dimensions[1].

2 Solar collectors

The high energy storage performance and efficiency have led to plan thermal applications which increased attention of the research in the field of solar energy. A solar collector has ability to convert the solar energy to the working fluid thermal energy for applications of solar energy and also directly to an electrical energy for the applications of Photovoltaic. The applications of solar heating were absorbed as heat by solar collector which was transported to the operation liquid. The heat transferred by the liquids may be utilized for heating to provide local hot water, or to benefit the heating storage trough which might be used the heat later (for cloudy days or night). For applications of PV, it was not only converted the solar radiation to electrical energy, but the plenty of waste heat production, which was recovered for heating utilized by PV the board attaching with recovering the working liquids filled tube [2].

2.1. The non-concentrating collectors

a. Flat plate collectors

The solar collectors with flat plate were always faced to direction, and also, need to be on proper faced. A flat plate solar collector permanently included to covers with glass, plates for absorber, layers for insulation, recuperating tubes and other auxiliaries. The cover with glass reduced convective losses from the plate absorber, and also reduced the collector radiation losses cause to the influence of

greenhouse. The reason to consider a desirable material glazing as low iron glass was high transmittance relatively for solar heating approximately from 0.85 to 0.87 and the necessary low transmittance for the long wave solar radiation from 5.0 lm to 50 lm [3,4]. Hellstrom et al. [5] was performed the effect of thermal properties and optical on the solar collectors with flat plate performance and concluded that the efficiency enhance by 5.6% at 50°C when adding of a Teflon film as second glass layer, whereas a Teflon honeycomb installation for decrease the loss of convective was provide the overall efficiency by 12.1%. Furthermore, the glazing cover antireflection treatment was provided the output by 6.5% at 50°C working temperature. Coating the plate absorber with blackened surface for absorption too much possible heat; however various color coatings was reported in the literatures [6-8].
Selective surfaces desirable was consisted of an upper thin layer which was absorbed maximum solar intensity with shortwave and approximately transferred to thermal radiation with long wave, and the lower layer that was the low emittance and the high reflectance for high wave radiation. Some desirable optical surfaces efficiency selective normally production a high cost, but several low cost production ideas were also reported [9]. Likewise, the solar plate for enhancing thermal efficiency, the absorber losing heat also needs to decrease. Francia [10] was studied that the insertion of honeycomb, which was consisted of transparent material with faced to the gap air between the absorber and glazing which also, reduced the heat loss. The absorbing heat by the plate absorber should be rapidly transported to liquids for preventing the system of the overheating [11]. Kumar and Reddy [12] were introduced the solar receivers heat transfer with porous medium and concluded heat transfer enhancement significantly by 64.3%. Lambert et al, [13] were studied that the flow oscillation may significantly increase the heat transfer when thermal diffusivities improving of the solar collector's fluids. Ho et al. [14] were presented a structure of double pass to receive solar and benefit a best heat transfer rate.

b. Hybrid PVT collectors
Hybrid photovoltaic thermal collectors (PVT) [15] have converted solar radiation into heat and electricity directly. A typical (PVT) collector included to a PV module of an optimum performance with range of 5%-20% and plate absorber (acting as a heat removal device) with PV back module. The plate heat removal cooled the module of PV down to a proper temperature for high electrical efficiency, with same time; it collected the waste heat, that may use for low temperature applications, as adsorption cooling systems and production hot water (washing and showering) [16]. Recently, most of the significant researches on PVT collectors were related to collectors of flat plate. Many investigations were focused to tube dimensions and absorber plate [17], rates of fluid flow [18,19], size of tank [20], packing factor of PV cell [21], amorphous silicon using [22, 23], metal fins using [24], and multiple passage configurations [25]. The numerical method for these collectors has been developed; the complicated balance between electrical and thermal outputs was studied [17, 26, 19, and 27]. Furthermore, the PVT collector's exergy analysis, based to the second Law of Thermodynamics, was mentioned by Joshi and Tiwari [28].

3 Types of Solar Air Heaters
Solar air heaters can be divided into two main parts. The first part was related to the flow configuration of air channel. Flow configurations of various air channels may be constructed to enhance the system efficiency. These configurations can be expressed in four sub titles under this subject. The sub title were; single flow single pass, double flow single pass, single flow double pass and single flow recycled double pass. The second part was related to the design air channel. The air channel design affects the system efficiency significantly. For that reason various design configurations may be utilized in the solar collectors. The second category may also be expressed in three subtitles such as; flat plate, extended surface assisted, porous media assisted. All main and sub titles were explained below.

4 Classification According to Air Channel Flow Configuration
a. Single Flow Single Pass
Experimental study of solar air heater using porous media has been conducted by [29]. They concluded the effect of mass flow rate and solar radiation on efficiency of solar collector. Single flow single pass was the most common and simplest type of solar air heater as shown in Figure 1. Generally, a black plate has been utilized for a high rate of solar absorption and as a selective absorber plate. The air flow channel was insulated on the bottom and lateral sides for preventing heat loss to the surroundings. The insulation materials may be glass wool, polyurethane or rock wool. The solar radiation passes through the transparent cover and was

absorbed by the absorber plate. The temperature of the absorber plate was increased since its bottom was insulated. Heat was transferred from the heated absorber plate to the air flowing into channel. In the single flow single pass solar collector, there was an inlet and outlet for the air to enter and leaved the channel directly. That was why this kind of solar air heater was named as "single flow single pass" for many investigators [30-32].

b. Double Flow Single Pass

The double flow solar air heater performance was studied and compare with the performances of single pass and found that double pass operation increases the efficiency of solar collector [33]. The double flow single pass solar air heater was very similar to the single flow single pass heater. The main difference between them was the number of air flow channels. In the double flow single pass solar air heater, there were two air channels as indicated in Figure 2. The top channel included of a solar absorber and a cover glass. The second channel located on the bottom of the first channel included of the same absorber plate (on top) with insulation (on bottom). The air was entered the collector as divided; half passes through the upper channel while the remainder flows through the bottom channel. For both channels, the airflow enters the channel and directly leaves it. That was why this kind of solar air hearer was defined a "double flow single pass". Using a double flow single pass solar air heater enhance the heat transfer area and the thermal performance of the system can be higher than a single flow single pass model with the same flow rate [34].

c. Single Flow Double Pass

The main goal of utilizing double pass arrangement is to reduce the heat loss to surrounding from the front collector face and also improving the thermal performance of the system [35]. Gonzalez et al., (2012) [36] studied the thermal efficiency of a double pass solar air heater which designed and manufactured at INENCO experimentally, and the thermal model developed to describe its thermal behavior theoretically. The results illustrated a temperature rise of 35°C with respect to the inlet air temperature, for a solar radiation on the collector plane around 900 W/m^2. The average daily efficiency of 34% has been concluded. Two overlapping air flow channels in a single flow double pass solar air heater were selected. Air flows at the upper channel, changes direction at the end of channel and enters the lower channel. It flows straight in the bottom channel. This is the main reason to define this type of solar air heater is a "single flow double pass". **Figure 3a** demonstrates one of them. It can be seen that there are two overlapping air flow channels. These channels are separated by a glass from each other and the absorber is placed at the bottom side of the lower channel. Air flows from the first and the second transparent sheet and is received by the absorber. The bottom side of the absorber is insulated. For the second design, the absorber plate is placed as a separator between the upper and lower channels as showed in **Figure 3b**. The upper air flow channel is formed by the glass cover and the absorber plate where the lower air flow channel has been located among the insulated lower plates and the same absorber plates [37].

d. Single Flow Recycled Double Pass

The using of recycled heated air in the solar air heater design can enhance its efficiency and adjust the air outlet temperature [38]. The partial circulation of the air heated may provide the desired air temperature at the exit of air flow if the temperature at outlet is different than the desired temperature.

4. Classification According to Air Channel Design

a. Flat Plate

The attention of researchers has given to analysis of flat plate solar heating by experimental work for cost and efficiency analysis of solar heating with two pass. A flat plate collector utilized to heat the air commonly known as a solar heating [39]. The type of the flat plate is the simplest form of solar air heater. This solar heating type consists of an absorber plate and one or more glass covers as shown in Figure 4. The solar heating sides except the glass cover must be well insulated for preventing the heat loss. Air may flow either under or over the absorber plate. Flat plate solar air heaters may be designed as single pass, double pass, double flow or recycled. The absorber plate has generally a smooth plate and it does not contain a fin, roughness element or obstacle. This reason to call this type of solar air heater is a "Flat Air Channel". The Flat Air Channel solar air heater construction is simple; hence it has a low cost. Since no mechanism or method is utilized to improve the channel heat transfer, this kind of solar air heater efficiency is lower than other types [40].

b. Porous Media Assisted

Many researches were focusing on the air heater performance enhancement by integrating flat plate collector with energy storage systems and packed bed [41]. The single pass solar heating and different porous media was conducted experimentally [42]. Their results indicated that the solar heating efficiency by using steel wool as a porous medium was higher than the glass wool as well as conventional air heater. The solar air heater channel with a porous medium assisted could be a useful way to improve the outlet air temperature and thermal efficiency. The packed bed utilization in solar air heater channel flowing was increased both the heat transport area and mixing of air stream. These solar heaters include an insulating material, a transparent cover, porous media and an absorber plate **Figure 5**. The porous media was inserted in the channel flow of the solar air heater. The air flows into a channel in contact with the porous media which was in contact with the absorber. Assistance of porous media heaters may be designed as single pass, double pass or recycled but they were generally single flow double pass systems. The porous media may be chosen from high conductive materials to accelerate heat transfer between the porous media and the air flows inside the channel. The porosity of the porous media was very important parameter to indicate a pressure drop in the channel. Though the porosity decreasing improves the effective heat transfer coefficient, it also increases the pressure drop through the channel. This is the reason to perform these studies on the characteristics of porous media required for designing a system with high heat transfer rate and low pressure drop. There is no doubt that with the optimum porosity, thickness and position, the heat transfer between absorber and air flow through the channel may be improve considerably [43].

5. Conclusions

The solar thermal applications are reviewed with focusing to the two main subsystems: heating energy storage subsystems and solar collectors. Many of solar collectors are discussed, consisting concentrating and non-concentrating types. For non-concentrating collectors, the PVT solar collectors conclude the best efficiency. Heat transfer augmentation has necessary to overcome the low heat transfer for these applications. For this purpose, graphite composites and metal foams were studied to be the perfect materials. Finally, the current status of existing solar power stations is reviewed, with potential developments future research being suggested. The high temperature phase change materials with melting temperatures above 310°C were included. The promising substances consisted salt eutectics, pure inorganic salts, metals and metallic eutectic alloys. Number of pure inorganic salts and salt eutectics focused on the chlorides basis, nitrates and carbonates which have low cost. The assessment of the thermal properties of various phase change materials is studied. The applications of the heat storage utilized as a part of solar air heating systems, solar water heating systems, solar green house, solar cooking, space heating and cooling buildings application, off peak electricity storage systems, waste heat recovery systems. This review paper also introduces the melt fraction studies of the few identified phase change materials utilized in many storage systems applications with different heat exchanger container materials. The research and development is based and productive, concentrating on both the resolution of specific phase change materials and problems and the study of the characteristics of new materials. This review paper appears the different heat transfer solution methods have been employed by different investigator. The experimental, theoretical and numerical studies have been carried out on the thermophysical properties of new materials with phase change. There are five pure inorganic salts based on nitrates and hydroxides with the range of 300-550◦C melting temperatures, the fusion latent heats of more potential phase change materials with the range of 300-550◦C melting temperatures in binary and ternary chloride eutectic salts. They also found the high latent heat of fusion, most of which were above 250 kJ kg−1. Identifying a suitable phase change materials has been one aspect in the development of a high temperature phase change thermal storage system. Another aspect and also a challenge were to improve the system thermal efficiency due to the low thermal conductivity of salts. The thermal performance augmentation methods employed in phase change thermal storage systems with high temperature. The thermo-hydraulic performance parameter can be improved by increasing the angle of attack of flow and relative roughness height.

References:

[1] Faisal M. and Ravindra M. Heat transfer enhancement of solar air heater by using artificial roughness double inclined ribs.IRJET 2016:3.2039-2044.

[2] De Winter F. Solar collectors, energy storage, and materials. Massachusetts: The MIT press; 1991.

[3] Khoukhi M, Maruyama S. Theoretical approach of a flat plate solar collector with clear and low-iron glass covers taking into account the spectral absorption and emission within glass covers layer. Renew Energy 2005;30:11.77–94.

[4] Parsons RA. ASHRAE Handbook: heating, ventilating, and air-conditioning applications. In: Chapter 30. Atlanta: ASHRAE; 1995.

[5] Hellstrom B, Adsten M, Nostell P, Karlsson B, Wackelgard E. The impact of optical and thermal properties on the performance of flat plate solar collectors. Renew Energy 2003;28:331–44.

[6] Tripanagnostopolous Y, Souliotis M, Nousia T. Solar collectors with colored absorbers. Sol Energy 2000;68:343–56.

[7] Wazwaz J, Salmi H, Hallak R. Solar thermal performance of a nickel-pigmented aluminium oxide selective absorber. Renew Energy 2002;27:277–92.

[8] Orel ZC, Gunde MK, Hutchins MG. Spectrally selective solar absorbers in different non-black colours. In: Proceedings of WREC VII (CD–ROM), Cologne, Germany; 2002.

[9] Konttinen P, Lund PD, Kilpi RJ. Mechanically manufactured selective solar absorber surfaces. Sol Energy Mat Sol C 2003;79:273–83.

[10] Francia G. A new collector of solar radiant energy. In: Proceedings of the united nations conference on new sources of energy, paper No. F6. Rome, Italy; 1961. p. 572.

[11] Slaman M, Griessen R. Solar collector overheating protection. Sol Energy 2009;83:982–7.

[12] Kumar KR, Reddy KS. Thermal analysis of solar parabolic trough with porous disc receiver. Appl Energy 2009;86:1804–12.

[13] Lambert AA, Cuevasa S, del Río JA. Enhanced heat transfer using oscillatory flows in solar collectors. Sol Energy 2006;80:1296–302.

[14] Ho C.D, Yeh H.M, Wang RC. Heat-transfer enhancement in double-pass flat plate solar air heaters with recycle. Energy 2005;30:2796–817.

[15] Aste N, Chiesa G, Verri F. Design, development and performance monitoring of a photovoltaic-thermal (PVT) air collector. Renew Energy 2008;33:914–27.

[16] Wang RZ, Zhai XQ. Development of solar thermal technologies in China. Energy 2012;35:4407–16.

[17] Bergene T, Lovvik OM. Model calculations on a flat-plate solar heat collector with integrated solar cells. Sol Energy 1995;55:453–62.

[18] Kalogirou SA. Use of TRNSYS for modelling and simulation of a hybrid PV-thermal solar system for Cyprus. Renew Energy 2001;23:247–60.

[19] Prakash J. Transient analysis of a photovoltaic thermal solar collector for cogeneration of electricity and hot air water. Energy Convers Manage1994;35:967–72.

[20] Agarwal RK, Garg HP. Study of a photovoltaic thermal system thermosyphonic solar water heater combined with solar cells. Energy Convers Manage 1994;35:605–20.

[21] Fujisawa T, Tani T. Optimum design for residential photovoltaic–thermal binary utilization system by minimizing auxiliary energy. Electr Eng Jpn (English Translation of Denki Gakkai Ronbunshi) 2001;137:28–35.

[22] Anonymous authors. New generation of Hybrid Solar PV/T collectors, prepared by LESO-PB/EPFL. Enecolo AG and Ernst Schweizer AG for the Swiss Federal Office of Energy; 2000. 1–55.

[23] Platz R, Fischer D, Zufferey MA, Anna Selvan JA, Haller A, Shah A. Hybrid collectors using thin-film technology. In: Proceedings of the 26th photovoltaics specialists conference (IEEE). Anaheim, CA, USA; 1997. p.1293–96.

[24] Tonui JK, Tripanagnostopoulos Y. Improved PV/T solar collectors with heat extraction by forced or natural air circulation. Renew Energy 2007;32:623–37.

[25] Hegazy AA. Comparative study of the performances of four photovoltaic/thermal solar air collectors. Energy Convers Manage 2000;41:861–81.

[26] Coventry J. Simulation of a concentrating PV/thermal collector using TRNSYS. In: Proceedings of the ANZSES solar energy conference, Newcastle, UK; 2002.

[27] Zondag HA, De Vries DW, Van Helden WGJ, Van Zolingen RJC, Van Steenhoven AA. The thermal and electrical yield of a PV-thermal collector. Sol Energy 2002;72:113–28.

[28] Joshi AS, Tiwari A. Energy and exergy efficiencies of a hybrid photovoltaic-thermal (PV/T) air collector. Renew Energy 2007;32:2223–41.

[29] Tina GM, Rosa-Clot M, Rosa-Clot P, Scandura PF. Optical and thermal behavior of submerged photovoltaic solar panel: SP2. Energy 2012;39:17–26.

[30] Palmer KF, Williams D. Optical properties of water in the near infrared. J Opt Soc Am 1974;64:1107–10.

[31] Robles-Ocampo B, Ruíz-Vasquez E, Canseco-Sánchezb H, Cornejo-Mezac RC, Trápaga-Martínezd G, García-Rodrigueza FJ, et al. Photovoltaic/thermal solar hybrid system with bifacial PV module and transparent plane collector. Sol Energy Mat Sol C 2007;91:1966–71.
[32] Nelson J. The physics of solar cells. London: Imperial College Press; 2003.
[33] Wei XD, Lu ZW, Wang ZF, Yu WX, Zhang HX, Yao ZH. A new method for the design of the heliostat field layout for solar tower power plant. Renew Energy 2010;35:1970–5.
[34] Medrano M, Gil A, Martorell I, Potou X, Cabeza LF. State of the art on high-temperature thermal energy storage for power generation. Part 2—Case studies. Renew Sust Energy Rev 2010;14:56–72.
[35] Battleson KW. Solar power tower design guide: solar thermal central receiver power systems. Sandia National Labs, Report SAND81-8005; 1981.
[36] Parabolic dish collector, http://www.geni.org/globalenergy/library/articles-renewable-energy-transmission/solar.shtml; 2012 [accessed 16.11.12].
[37] Choudhury C. (1999) "Performance and Cost Analysis of two pass Solar air Heater" Elsevier science Ltd.
[38] Alvarez, G., J. Arce, L. Lira and M.R. Heras (2004) " Thermal Performance of an Air Solar Collector with an Absorber Plate Made of Recycable ALuminium Cans" Solar Energy 77:107-113.
[39] Gaur G. An Experimental investigation of a novel design of double pass solar air heater. International Journal of chem. Tech Research vol.5pp 1036-1040.
[40] Gupta B., Waiker J.K., Manikpuri G.P., Bhalavi B.S., 2013. Experimental Analysis of Single and Double Pass Smooth Plate Solar Air Collector with and without Porous Media. American Journal of Engineering Research, 2(12): 144-149.
[41] BashiraAbdrubAirasoulYousef (2005) "Prediction Study on Single and Double flow Solar Air Heater " Suranaree J. sci. ATechnolpp 123-136.
[42] Moummi, N., S. Youcef-Ali, A. Moummi and J.Y. Desmons (2004) "Energy Analysis of Solar Air Collector with Rows of fins" Renewable Energy 29: 2053-2064.
[43] Ozturk, H.H. and Y. Demirel (2004). " Exergy-Based Performance Analysis of Packed Bed Solar Air Heaters" Internatioanl Journal of Energy Research 28:423-432.

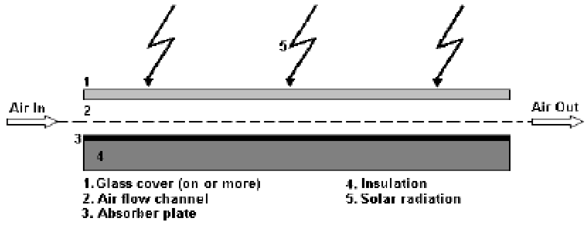

Figure 1. A schematic view of single flow single pass.

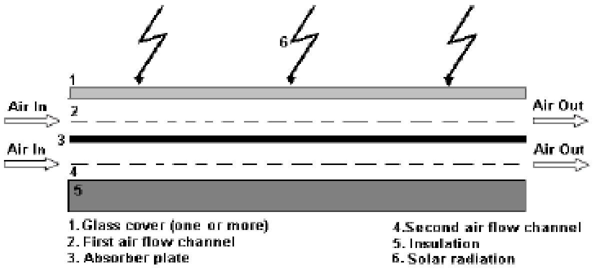

Figure 2. A schematic view of double flow single pass.

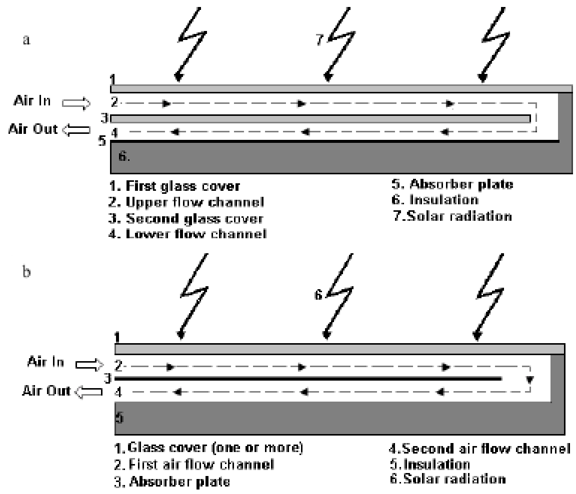

Figure 3. The single flow double pass with absorber plate, a) solar air heater with glass separator b) solar heating with absorber separator.

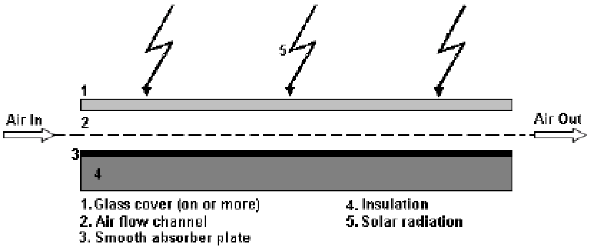

Figure 4. The flat plate solar air heater [40].

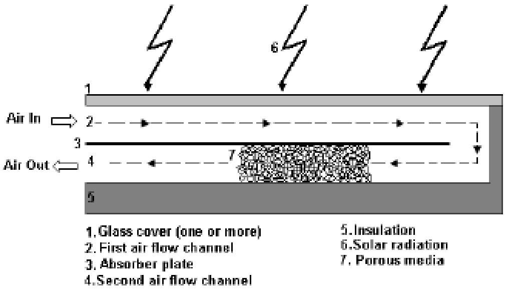

Figure 5. The porous assisted solar air heater [43].