Advancements In Solar Collector – A Review

Mr. Shubhashish Sarkar [1], Prof. K.S. Chaudhari [2]
[1]Dept of Mechanical Engineering
[2]Assistant Professor, Dept of Mechanical Engineering
[1, 2] G H Raisoni college of engineering Nagpur

Abstract- *Indian philosophers Siddharth Suman, Mohd. Kaleem Khan and Manabendra Pathak attempted to define the seemingly interesting concept regarding 'Solar Collector' in their 2015 Journal paper. This paper presents a brief idea regarding advancements made in the field of solar thermal technology with a focus on techniques employed for its performance enhancement. Performance enhancement techniques such as geometrical modifications on the absorber plate and use of solar selective have been given a special attention.*

Keywords- Solar Collector, heat transfer rate, wire coil, twisted tape.

I. INTRODUCTION

Recent increase in energy demand and constraints in supply of energy becomes a priority for the different industry. Rapid depletion of conventional energy sources and environmental degradation caused by their over exploitation, the renewable energy sources are believed to be the future. Technologies utilizing renewable energy sources differ significantly from one another, not only with regard to technical and economic aspects but also in relation to their reliability, maturity, and operational experience in utility scale conditions. Generation of energy from limited conventional sources has caused so much environmental degradation that impact is visible in the form of pollution, acid rain, global warming etc. Thus, there is a crying need for producing green and clean energy from renewable sources. Technologies used to harness solar energy have emerged as the most promising and mature since solar energy is abundant, freely available, and it has commercial potential too. The conversion of solar energy into different other forms i.e. mechanical, chemical etc. is evident in nature. There are two broad ways of utilizing the solar energy for the production of energy :(i) solar–electric conversion (converting solar energy directly into electrical energy using photovoltaic solar cell) and (ii) solar–thermal conversion (converting solar energy into thermal energy using solar collector).

II. EXISTING SYSTEM

1. Solar Collector:

Solar collector is a device that collects thermal energy of solar insolation by absorbing them. The thermal energy thus stored is carried away by a flowing fluid and utilized for some specific purposes. The classification of solar collector is given in fig 1.The solar collectors are broadly classified as non-tracking and tracking collectors. The non-tracking collectors are kept at rest and also known as fixed or stationary collectors, whereas tracking collectors are designed to track the movement of sun so that the incoming solar radiations always fall perpendicular to them. The tracking solar collectors are further classified as one axis tracking and two axes tracking collectors. Non-tracking collectors are categorized as flat plate, evacuated tube and compound parabolic collectors. Parabolic trough collector, cylindrical trough collector, and linear Fresnel reflector fall under the category of single axis tracking systems, whereas central tower receiver, parabolic dish reflector, and circular Fresnel lens belong to dual axes tracking systems.

2. Types of Solar Collector:

A flat plate collector consists of a transparent glass cover, an absorber plate with a parallel back plate as given in fig 2. Depending upon the type of fluid, that is air or water, the flow passage is designed. For air as a working fluid, the gap between the absorber plate and back plate is made passage for the flow of fluid. When water is used as a working fluid, the copper tubes brazed on the absorber plate are made flow passages.

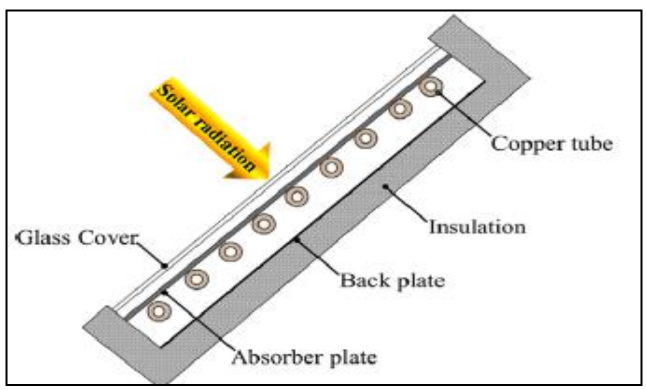

Figure 1. Flat Plate Collector

The evacuated tube collector (ETC) consists of a heat pipe kept inside a glass enclosure as given in fig 3. The heat pipe uses liquid like ethanol, methanol, water etc. to capture heat of solar insolation and this liquid transfer's heat to some other working fluid while undergoing evaporation–condensation cycles. On receiving solar radiation, the liquid inside the heat pipe undergoes phase change and it is converted into vapor, which rises toward the upper part of the heat pipe due to buoyancy. The vapor condenses back to liquid after transferring heat to the working fluid in the heat exchanger section at the top. The liquid flows

Back to the bottom of heat pipe due to gravity, and the cycle continues. The glass enclosure is evacuated to minimize the heat loss due to convection and to prevent climatic degradation of its inner materials, as the back plate is not required.

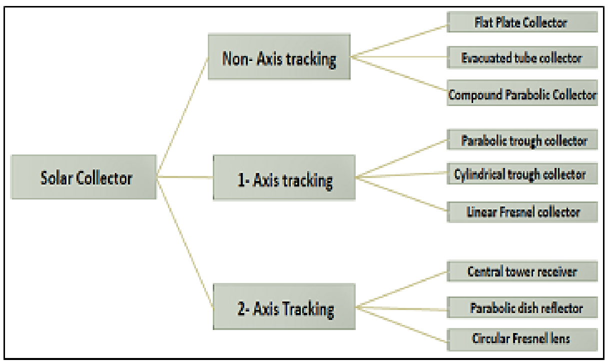

Figure 1. Classification of Solar Collector

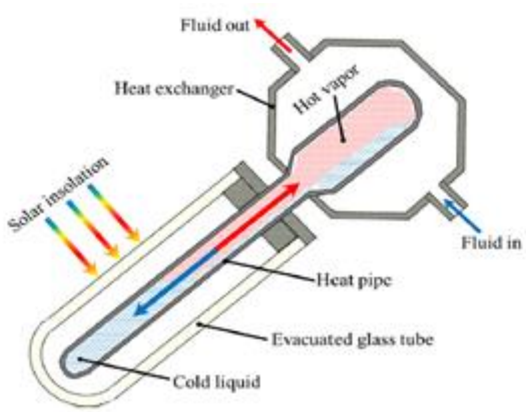

Figure 2. Evacuated Tube Collector

The compound parabolic collector (CPC) consists of a glass cover, an absorber tube and two parabolic reflecting surfaces as shown in Fig 4. The two parabolic reflecting surfaces 'A' and 'B' have their focal points lying on each other. The absorber tube is placed at the mid plane between the two focal points. The orientation of the parabolic reflectors should be such that the sun's position or angle of incidence has no effect on the performance of the collector. Thus, aligning the CPC's receiver or absorber tube along east–west line eliminates the need of tracking throughout the day.

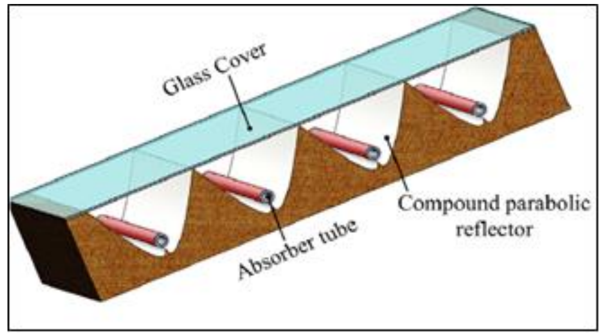

Figure 4. Compound Parabolic Collector

The parabolic trough collector consists of a parabolic reflecting surface with an absorber tube placed along its focal line as shown in Fig 5. The position of sun is tracked for normal incidence of solar radiations at any instant of time. Such collectors are used for energizing steam power cycles for electricity generation as the working fluid temperature can be of the order of 400 C. The parabolic trough collector is usually employed for large scale power generation.

III. TECHNIQUES TO IMPROVE PERFORMANCE OF SOLAR COLLECTOR

As the efficient removal of heat from the solar collectors is the prime objective of any solar thermal system. The performance of a solar collector depends upon how much a working fluid heat carries away the heat from the collector. This paper provides different techniques used to enhance the performance of the collectors. The performance enhancement of solar collectors was classified into three main groups: (a) increasing the heat transfer coefficient between the absorber plate/tube and the working fluid (i.e., artificially roughened absorber plates/tubes), (b) using special type of coatings on the absorber (i.e., solar selective coatings).

1. Increasing the heat transfer coefficient between absorber plate/tube and working fluid:

In principle, the heat transfer between a fluid and a solid surface is increased by increasing the contact area (i.e. extended surfaces) and by creating turbulence, which promote mixing between the various fluid layers. The nature of working fluids actually governs the type of geometrical modification to be made in the absorber assembly. If the working fluid is air or gas, which has very low convective heat transfer coefficient, the extended surfaces/fins/corrugations are provided on the absorber plate. For water or liquid as the working fluid, twisted tapes/perforated tapes/wire coils, inserts/ baffle plates, and internally finned tubes are provided to generate turbulence, which eventually increase heat transfer coefficient.

Different Professors summarized the studies on the use of various roughness geometries and their other quantitative parameters.Bhagoria experimentally investigated transverse wedge shaped rib having relative

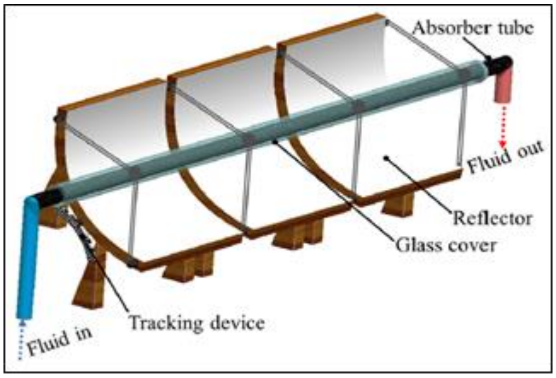

Figure 5. Solar Parabolic trough Collector

height in range of 0.015–0.033 and varied the wedge angle from 81 to 151. The ribs yielded Nusselt number up to 2.4 times and the friction factor increased up to 5.3 times in comparison to that of smooth duct. The maximum heat transfer takes place for a relative roughness pitch of about 7.57 and at a wedge angle of 101. The correlations developed for Nusselt number and friction factor are within the error limits of 15% and12%, respectively. Jaurker performedexperimental investigation on heat transfer and friction characteristics of a solar air heater using rib-grooved artificial roughness to find optimized conditions for its performance. It is observed thatrib-grooved arrangement provides the best thermo-hydraulic performance and yields Nusselt number up to 2.7 times, while the friction factor rises up to 3.6 times. The optimized groove position to pitch ratio is determined to be 0.4, and the correlations developed for the Nusselt number, and the friction factor are found to be within deviations of 2.73% and 3.16%, respectively.

In water heaters, the heat transfer rate is increased by using turbulence promoters such as twisted tape inserts, perforated twisted tape inserts, wire coil inserts, wire mesh etc. in the flow passage. They discussed the flow patterns of each shape along with Nusselt number and friction factor correlations which are shown in the table 1.

Garcia et. Al. [1] used steel wire coil inserts to evaluate the in-tube heat transfer coefficient using water and water–propylene glycol as working fluids. The tests were conducted for laminar-transition-turbulent regimes. They found that the heat transfer rate increased by 200% for constant pumping power. It was also observed that the maximum enhancement occurred in transition regime. On the basis of these findings, later Garcia implemented wire coil inserts in the flat plate solar water heater. The tests were conducted for different mass flow rates in the range 0.011–0.047 kg/s. It was found that the wire-coil inserts increased thermal efficiency of the collector. 14–31% increase in average thermal efficiency was reported for the mentioned range of mass flow rate. However, for higher mass flow rates, the increase in heat transfer rate was not significant. Jaisankar et.al. [2] performed experiments on helical twisted tape inserts with different twist ratios inside the copper tubes of flat plate solar water heater to determine the heat transfer and pressure drop characteristics. They used twisted tapes made up of copper. The Reynolds number was varied from 3000 to 23,000. It was found that with the increase in twist ratio, the swirl generation decreased resulting in both heat transfer rate and pressure drop. The use of twisted tapes reduced the collector area requirement by 8–24% for a given efficiency. Promvonge et.al. [3] used twin twisted tapes inside a helicalribbed tube of double tube heat exchanger. The direction of both (tube and tapes) structural modifications was designed to create a co-swirl of the fluid. They found an improved overall performance with the proposed design compared to individual modifications. The highest thermal efficiency was achieved for twist ratio of eight. It has been seen that the use of various types of inserts increases the heat transfer as well as pressure drop. A modification in the twisted tape by perforating it is expected to reduce the pressure drop and increase the turbulence further.Garcia et.al.[4] implemented wire coil inserts in the flat plate solar water heater. The tests were conducted for different mass flow rates in the range 0.011–0.047 kg/s. It was found that the wire-coil inserts increased thermal efficiency of the collector. 14–31% increase in average thermal efficiency was reported for the mentioned range of mass flow rate. However, for higher mass flow rates, the increase in heat transfer rate was not significant. Azmi et.al. [5] used aluminum made twisted tapes with a different test fluid. The test fluid was TiO_2/water nanofluid for concentrations ranging from 0% to 3%. It was found that the heat transfer coefficient increased by a maximum of 23.2% at 1% concentration of nanoparticles. The increase in twist ratio caused a decrease in heat transfer coefficient. The thermo-hydraulic performance analyses showed that maximum advantage of both nanofluid and twisted tape inserts occurred at twist ratio of 15 and concentration of 1%.

Table 1. Heat Transfer enhancement in water heaters

Author (Year)	**Structural Modification**		**Range of Parameters**	**System**	**Test Fluid**
	Shape	**Material**			
Garcia A. (2005) [1]	Wire coil	Steel	Re : 80-90; 000 e=d ¼ 0:07-0:10 d ¼ 18 mm p=d ¼ 1:17-2:68 p=e ¼14-33	Heat Exchanger	Water, Water propylene glycol
Jaisankar S. (2009) [2]	Helical twisted tapes	Copper	Re : 6000-60; 000 e=DH ¼ 0:06 p=DH ¼0:27 Y ¼ 2:17-9:39 Co-swirl with helical	Solar water tube (Copper tube)	water
Promvonge P. (2012) [3]	Twin twisted tapes coupled with helical ribbed	Aluminum	L ¼1:5 m di ¼ 16 mm do ¼19 mm Re : 8000-30; 000 ϕ ¼ 0-3% H=D¼ 0-15	Heat Exchanger (Double copper tube)	water
Garcia A. (2013) [4]	Wire coil	Steel	m : 0:011-0:047 kg=s	Solar water heater (Copper tube)	water
Azmi WH. (2014) [5]	Twisted tape	Aluminum	L ¼1:5 m di ¼ 16 mm do ¼19 mm Re : 8000-30; 000 ϕ ¼ 0_3% H=D¼ 0_15	Solar water tube	TiO2/Water Nano fluid
Nanan K. (2014) [6]	Perforated helical twisted-tapes	Aluminum	Re : 6000-20; 000 d=w ¼ 0:2; 0:4; 0:6 s=w ¼ 1; 1:5; 2 P=D ¼ 2 y=w ¼ 3 e=D ¼ 0:03	Heat Exchanger	water
Sandhu G. (2014) [7]	Twisted tape, wire coil and wire mesh	Steel and copper	Re : 200-8000 L ¼0:915 m di ¼ 13:4 mm do ¼ 16 mm	Solar water heater (Copper tube)	water

2. Using special type of coatings on the absorber (i.e., solar selective coatings):

Another efficient way to maximize the harnessing of solar insolation is to apply coatings of some specific materials on the absorber surface. Coatings are broadly classified as non-selective coatings, and solar selective coatings. In solar thermal application, a coating should have a high absorptivity but a low emissivity, so that it retains the trapped thermal energy. Recently Prof. Tulchinskyetal synthesized a new non-selective coating formed by thermal reaction of sol–gel Titania with copper manganese spinel. This novel thermal coating Cu0.44Ti0.44Mn0.84Fe0.28O3 exhibits bixbyite structure and has an absorptivity of greater than 95% in the visible range. This coating can be applied with ease either manually or by spray technique. It has potential to be employed for solar thermal conversion.

According to Planck's law, the photonic energy of radiation is inversely proportional to its wavelength. This means a body at high temperature will emit thermal radiation at shorter wavelength and vice-versa. Thus, the incoming solar radiation has shorter wavelength and thermal radiation emitted by the absorber surface will obviously have longer wavelength. The solar selective coatings allow incoming Solar radiation to pass through it and block the emittance of longer wavelength thermal radiation. Thus, they help in capturing the radiative energy to achieve high temperatures. There are many types of coatings based on different absorption mechanisms such as light trapping, particulate coatings, semiconductor-metallic layers, multi-layer films, quantum size effects, and intrinsic absorption. Besides having a long-term thermal stability, these coatings should have high absorptivity in the 0.3–2.5 mm spectral range and low emissivity in the far infrared range (0.7 mm onwards) for given operating range of temperature. The optical characteristic of a coating is defined in terms of 'solar selectivity', which is the ratio of solar absorptivity to emissivity at a given temperature. By improving the optical characteristic and making it thermally stable at high temperatures will eventually increase the working fluid temperature, thereby improving the overall efficiency of solar collectors. Research made by different individuals on different types of solar selective coatings is shown in Table 2.

Table 2. Selective experimental studies on solar selective coatings

Author (Year)	**Material**		**α**	**ε**	**Technique used**	**Conclusions**
	Substrate	**Coating**				
Abbas A. (2000) [8]	Nickel plated copper	Black chrome	0.96	0.12	Electrochemical treatment	-Make solar collectors better efficient thermally by more than 30%. -Good thermal stability up to 300® C
Schuler A. (2000) [9]	Aluminum	a-C:H/Ti	0.876	0.06	PVD/PECVD	-Selectivity as high as 14.4 is achieved without optimizing thickness. - Service life is predicted to be more than 25 years.
Teixeira. (2001) [10]	Glass, Aluminum and Copper	Cr–Cr2O3/ Mo–Al2O3	0.88–0.94	0.15–0.04	Magnetron sputtering	-Composite coatings offer excellent thermal stability -Need to optimize the optical behavior of coatings by simulation.
Farooq and Hutchins (2002) [11] [12]	Copper and aluminum	V-Al2O3	0.98	0.02	Magnetron sputtering	-Number of layers were insignificant beyond a critical number. -Four layer PGSAC gives the best efficiency.
Cinderella L.(2007) [13]	Nickel-plated copper	Co–Cd/Ni–Cd	0.93	0.07	Electro-deposition	-Selective coating is required essentially only for flat plate collectors. -Low emittance coating required for unity concentration ratio systems.
Shashikala AR. (2007) [14]	Nickel-plated aluminum alloy	Black Ni–Co	0.948	0.17	Electrochemical treatment	-Nickel undercoat influences the optical properties substantially -Suitable for space applications too.
Wazwaz A. (2010) [15]	Aluminum alloy	Ni	0.892	0.052	Electrochemical treatment	-Average thermal efficiency increases with increase in Nickel content. -Exists an optimum limit of nickel that gives the optimum efficiency.
Juang R. (2010) [16]	Glass	SS/SS-N	0.91	0.06	Magnetron sputtering	-Fabricated high solar selectivity composite coating by the use of only one sputtering target having flexibility to

						control thickness of layers.
Du M. (2011) [17]	Silicon	Ti0.5Al0.5 N/ Ti0.25Al0.7 5	0.945	0.04	Magnetron sputtering	-Metallic character is exhibited by Ti0.5Al0.5N and resembles Na–Cl. -Semi conducting characteristics exhibited byTi0.25Al0.75
Liu Y. (2012) [18]	Copper and stainless steel	NbTiON/ SiON	0.95	0.07	Magnetron sputtering	-Oxidation and diffusion of copper degrades film at high temperature. -Coating on SS exhibits better thermal stability above 500® C.

Thermal properties of liquids play a decisive role in heating as well as cooling applications in industrial processes. Thermal conductivity of a liquid is an important physical property that decides its heat transfer performance. Conventional heat transfer fluids like water, oil, ethylene glycol etc. have inherently poor thermal conductivity, which makes them unfit for applications where high heat transfer rate is required. If the particulate size of solid additive is kept in order of micrometer or larger, it has the drawbacks of particle sedimentation, corrosion of components of systems, particle clogging, excessive pressure drop etc. These problems get reduced significantly if the particle size of solid phase is of order of nanometer, and this gave rise to a fluid known as Nano fluid. Nano fluids are dilute liquid suspensions of nanoparticles with at least one of their principal dimensions smaller than 100 nm. Due to very small sizes and large specific surface areas its having many superior properties like minimal clogging in flow passages, long-term stability and homogeneity. To achieve a stable Nano fluid, the particles should be dispersed in base fluids with no or very little agglomeration. This can be done through various methods, including electrical, physical, or chemical. The commonly used dispersion technique is ultrasonic or stator–rotor method.

IV. CONCLUSION

Due to the increase in the use of conventional energy resources the resources are decreasing day by day. Therefore there is a dire need of the Non- Conventional energy resources. Non- Conventional energy resources i.e. solar energy can help us in fulfilling the needs. Products such as Solar Parabolic Collector can helps in generating power supply, heating water etc. which can be used in various places in efficient manner. But some of the problems which leading to the decrease in the efficiency of the system need to be solved. This can be carried out by increasing heat transfer enhancement of the system and by using proper selective coating. By taking these point into consideration the efficiency of solar collector can be increased.

REFERENCES

[1] Garcia A, Vicente PG, Viedma A. Experimental study of heat transfer enhancement with wire coil inserts in laminar-transition-turbulent regimes at different Prandtl numbers. Int J Heat Mass Transf 2005; 48:4640–51.

[2] Jaisankar S, Radhakrishnan TK, SheebaK N.Experimental studies on heat transfer and friction factor characteristics of forced circulation solar water heater system fitted with helical twisted tapes. Sol Energy2009; 83:194–952.

[3] Promvonge P, PethkoolS, Pimsarn M, Thianpong C. Heat transfer augmentation in a helical-ribbed tube with double twisted tape inserts. Int Commun Heat MassTransf2012; 39:953–9.

[4] Garcia A, Martin RH, Garcia JP. Experimental study of heat transfer enhancement in a flat-plate solar water collector with wire-coil inserts. Appl Therm Eng 2013; 61:461–8.

[5] Azmi WH, Sharma KV, Sarma PK, Mamat R, Anuar S. Comparison of convective heat transfer coefficient andfrictionfactorofTiO2 Nano fluid flow in atubewithtwistedtapeinserts.IntJThermSci2014;81:84–93.

[6] Nanan K, Thianpong C, Promvonge P, Eiamsaard S. Investigation of heat transfer enhancement by perforated helical twisted-tapes. Int Commun Heat Mass Transf 2014; 52:106–12.

[7] Sandhu G, Siddiqui K, Garcia A. Experimental study on the combined effects of inclination angle and insert devices on the performance of a flat-plate solar collector.IntJHeatMassTransf2014;71:251–63.

[8] Abbas A, Sol chrome solar selective coatings-an effective way for solar water heaters globally.RenewEnergy2000; 19:145–54.

[9] Schuler A, GengJ, Oelhafen P, Brunold S, Gantenbein P, Frei U. Application of titanium containing amorphous hydrogenated carbon films (a-C:H/Ti) as optical selective solar absorber coatings. Sol Energy Mater Sol Cells 2000; 60:295–307.

[10] Teixeira V, Sousa E, Costa MF, Nunes C, Rosa L, Carvalho MJ, etal. Spectrally selective composite coatings of Cr–Cr2O3 and Mo–Al2O3 for solar energy applications. Thin Solid Films 2001; 392:320–6.

[11] Farooq M, Hutchins MG. A novel design in composites of various materials for solar selective coatings. Sol Energy Mater Sol Cells 2002; 71:523–35.

[12] Farooq M, Hutchins MG. Optical properties of higher and lower refractive index composites in solar selective coatings. Sol Energy Mater Sol Cells 2002; 71:73–83.

[13] Cinderella L., The real utility ranges of the solar selective coatings. Sol Energy Mater Sol Cells2007; 91:1898–901.
[14] Shashikala AR, Sharma AK, Bhandari DR. Solar selective black nickel–cobalt coatings on aluminum alloys. Sol Energy Mater Sol Cells 2007; 91:629–35.
[15] Wazwaz A, Salmi J, Bes R. The effects of nickel-pigmented aluminum oxide selective coating over aluminum alloy on the optical properties and thermal efficiency of the selective absorber prepared by alternate and reverse periodic plating technique. Energy Convers Manag 2010; 51:1679–83.
[16] Juang R, Yeh Y, Chang B, Chen W, Chung T. Preparation of solar selective absorbing coatings by magnetron sputtering from a single stainless steel target. ThinSolidFilms2010; 518:5501–4.
[17] Du M, Hao L, Mi J, Lv F, Liu X, Jiang L, et al. Optimization design of Ti0.5Al0.5N/ Ti0.25Al0.75N/ AlN coating used for solar selective applications. Sol Energy Mater SolCells2011; 95:1193–6.
[18] Liu Y, Wang C, Xue Y. The spectral properties and thermal stability of NbTiON solar selective absorbing coating. Sol Energy Mater Sol Cells 2012; 96:131–6.