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Kneza Miloša 7a/II,
11000 Beograd

**Predsednik Društva za
obnovljive izvore
električne energije
pri SMEITS-u**
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Za izdavača
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FOREWORD

Intensive technological development, improved standard of living and population growth on Earth demand an increasing consumption of all forms of energy and, on the other hand, cause negative effects on the environment.

Having this in mind, the United Nations have defined the sustainable economic development in the Millennium Development Goals, and the presidents of seven most developed countries, so called G7 Group, signed the declaration in Brussels, in which, inter alia, they emphasised the following goals:

- *reduction of greenhouse gas (GHG) emissions,*
- *improvement of energy efficiency, and*
- *promotion of the use of clean and sustainable energy technologies and continuation of investment in innovations.*

Particularly negative effects on the environment come from the electricity generation plants, taking into account that they are fuelled by fossil fuels. Therefore, the increased use of renewable electrical power sources is expected in the following period, both globally and in this country.

The main goal of the 5th international conference on renewable electrical power sources is to analyse the comparative advantages and disadvantages of modern solutions in the field of renewable electrical power sources used globally and in this country, and to provide a constructive platform for the exchange of competent opinions and ideas related to the development and use of these sources.

This international conference is for the fifth time organised by the Society for Renewable Electrical Power Sources, which has been a part of SMEITS (Serbian Union of Mechanical and Electrical Engineers and Technicians) since 2010.

Belgrade, October 2017

PREDGOVOR

Intenzivan tehnološki razvoj, rast životnog standarda i porast broja ljudi na Zemlji, zahtevaju sve veću potrošnju svih vidova energije, dok se na drugoj strani kao posledica, javljaju negativni efekti po životnu sredinu. Imajući ovo u vidu, UN su definisale održiv ekonomski razvoj u Milenijumskim ciljevima a predsednici sedam najrazvijenih država, takozvane Grupe G7, potpisali su deklaraciju u Briselu u kojoj su, između ostalih, istakli i sledeće ciljeve:

- *smanjenje emisije gasova staklene bašte,*
- *unapređenje energetske efikasnosti, i*
- *promovisanje primene čistih i održivih energetskih tehnologija i nastavak ulaganja u istraživanja i inovacije.*

Posebno negativan uticaj na životnu sredinu imaju postrojenja za proizvodnju električne energije imajući u vidu da kao pogonsko gorivo uglavnom koriste fosilna goriva. Zbog toga se u svetu, kao i kod nas, u narednom periodu očekuje povećanje primene obnovljivih izvora električne energije.

Osnovni cilj 5. Međunarodne konferencije o obnovljivim izvorima električne energije jeste da se analiziraju uporedne prednosti i nedostaci savremenih rešenja u oblasti obnovljivih izvora električne energije koja se primenjuju u svetu i kod nas, i da se obezbedi plodotvorna razmena kompetentnih mišljenja i ideja vezanih za razvoj i primenu ovih izvora.

Ovaj međunarodni skup po peti put organizuje Društvo za obnovljive izvore električne energije koje u okviru Saveza mašinskih i elektrotehničkih inženjera i tehničara Srbije (SMEITS) postoji od 2010. godine.

U Beogradu, oktobra 2017.

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НАНОМАТЕРИЈАЛИ И НАНОФЛУИДИ – НОВИ МАТЕРИЈАЛИ ЗА СОЛАРНЕ СИСТЕМЕ ИНТЕГРИСАНЕ У ОМОТАЧ ЗГРАДЕ

NANOMATERIALS AND NANOFUIDS – NEW MATERIALS FOR BUILDING INTEGRATED SOLAR THERMAL SYSTEMS

Danijela NIKOLIĆ¹, Jasmina ŠKERLIĆ, Jasna RADULOVIĆ,
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Solarna energija ima značajan uticaj na životnu sredinu, pa je razvoj novih tehnologija na ovom polju važan iz brojnih razloga. Sa naglim razvojem tehnologije poslednjih decenija XX veka, došlo je do pojave velikog broja novih materijala pogodnih za primenu u solarnim termalnim sistemima integrisanim u zgrade (building integrated solar thermal systems - BISTS). Nanotehnologija je pružila nove mogućnosti za razvoj nano-električnih uređaja kod primena u solarnim sistemima. Nanomaterijali i nanofluidi su pokazali veoma interesantne osobine o kojima je pisano proteklih decenija. Posebne osobine ovih materijala nude ogroman potencijal za mnoge primene, uključujući i BISTS. Nanotehnologija, ili kako se još "trterča generacija fotonaponske tehnologije" se koristi za povećanje efikasnosti konverzije solarnih celija. Nanomaterijali su veoma efikasni u fotonaponskim sistemima dok nanofluidi imaju veliki potencijal za termičke solarne aplikacije, posebno zbog povećanja specifične toplosti i termičke provodljivosti. Ovaj rad predstavlja pregled poslednjih publikacija o korišćenju novih materijala u zgradama – nanomaterijala i nanofluida, njihove aplikacije u zgradama, kao i analizu njihovih termičkih performansi.

Ključне речи: Nanomaterijali; Nanofluidi; BISTS

Solar energy has a significant impact on the environment, so the development of new technologies in this field is very important for many reasons. With the great development of technology in the last decades of the XX century, there has been an appearance of numerous new materials suitable for use in building integrated solar thermal systems (BISTS). The nanotechnology has brought new opportunities for the development of nanoelectronic devices for solar cell applications. Nanomaterials and nanofluids have shown many interesting properties which have been reported in the past decades. The distinctive features of these materials offer unprecedented potential for many applications, including application in BISTS. Nanotechnology or sometimes referred as "third generation PV" is used in order to help increase conversion efficiency of solar cell. Nanomaterials are very effective in PV applications, while nanofluids have a great potential for solar thermal applications, especially because of their specific heat and thermal conductivity increasing. This paper reviews some latest publications on the use of new materials in buildings - nanomaterials and nanofluids, current building applications and their thermal performance analyses.

Key words: Nanomaterials, Nanofluids, BISTS

1 Introduction

Nowadays, the most important energy consumer of heat and electricity is building sector. Existing buildings have to be suitably renovated, following energy sustainability investigations and aiming to the reduction of energy consumption. At the other side, new buildings should be constructed in the frame of the rules for Zero Energy Buildings. Towards zero energy consumption concept for the new buildings, there are steps to solar thermal collector and PV module design and operation improvements, considering building integration requirements. In order to reach these targets, new type of solar energy systems for domestic hot water production, space heating, cooling and lighting of the buildings

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are required. In addition to solar thermal collectors, photovoltaics have been installed on buildings and in a large variety [1].

In the last years, it has been developed the new tendency in building sector - to integrate solar thermal technologies into the building envelope (roof or façade). These systems are known as Building-Integrated Solar Thermal Systems (BISTS) [2]. BISTS systems also cover other types of solar systems such as Photovoltaic (BIPV) and Photovoltaic/Thermal (BIPVT).

Incorporation of BISTS, including active and passive solar energy systems, enables a rapid decrease of energy consumption in buildings. Improved technologies for collecting solar energy and converting it into useful heat (thermal systems) and electrical energy (photovoltaic systems), and combined PVT (photovoltaic/thermal systems) with appropriate energy storage solutions can promise providing the total energy needs (heating and cooling energy and electricity) of buildings in low latitude countries.

Due to its high efficiency, silicon is the leading material and it is the most commonly used material in solar cells technology. The first generation of solar cells corresponds to the most commercially available crystalline silicon, while second generation corresponds to thin film technology of solar cells, which first were based on amorphous silicon, and after silicon, the new technologies were developed based on compounds of cadmium sulphide, cadmium telluride, cuprous sulphide, gallium arsenide, copper indium gallium selenide/copper indium selenide and dye-sensitized solar [3].

But, it is very important to use new materials, special glazing and cladding structures, which aim to contribute to solar control of the building. These materials are combined with solar thermal collectors and photovoltaics and are considered necessary for the improvement of energy behavior of buildings, giving at the same time a new visage to them.

The fast paced technology development during the last decades, led to the appearance of several new solutions suitable for use in solar thermal systems, such as phase change materials (PCMs) and nanotechnology [4]. Nanotechnology implies the application of nanomaterials and nanofluids, which will be described in this paper.

2 Nanomaterials

New opportunities for the development of nanoelectronic devices for solar cell applications were brought by nanotechnology as new technology in processing PV solar cell. Characteristics of bulk materials are substantially different than semiconductor particles with dimensions in nanometer range. Due to quantum confinement effects in nanocrystalline semiconductors an effective increase in bandgap is achieved. As energy band-gap can be controlled by nanoscale components, nanotechnology referred as “third generation PV” is used to help increasing conversion efficiency of solar cell [5]. There are three devices used in nanotechnology for PV cell production: carbon nanotubes (CNT), quantum dots (QDs) and “hot carrier” (HC). The advantages of nanotechnology are:

- Enhance material mechanical characteristic,
- Low cost,
- Lightweight and
- Good electrical performances.

2.1 Carbon nanotubes (CNT)

Carbon nanotubes (CNT) are constructed of a hexagonal lattice carbon with excellent mechanical and electronic properties [6]. With n lines and m columns the nanotube structure is a vector which defines how the graphene (an individual graphite layer) sheet is rolled up. Nanotubes can be metallic or semiconducting. CNTs provide the highest spectral absorptivity (particularly on a per unit mass basis) over the entire solar range and they are present in different forms: single-walled carbon nanotubes (SWCNTs), double-walled carbon nanotubes (DWCNTs) and multi-walled carbon nanotubes (MWCNTs) (Fig 1) [6]. SWCNTs are formed by wrapping a one-atom-thick layer of graphene into a seamless cylinder while DWCNTs and MWCNT are formed by concentrically wrapping two and multiple layers of graphite, respectively [7].

A p-n junction which generates electrical current is formed of PV nanometer-scale tubes coated by special p and n type semiconductor materials and this methodology improves and increases the surface area available for electricity production. CNTs can be used as reasonably efficient photosensitive materials as well as other PV materials.

Nanotubes are currently used as the transparent electrode for efficient, flexible polymer solar cells. Naphthalocyanine (NaPc) dye-sensitized nanotubes have been developed. These resulted in higher short circuit current, while the open circuit voltage is reduced. Totally inorganic based nanoparticle solar cells, based on nanoparticles of CdSe, CdTe, CNTs and nanorods made out of the same material are studied by number of research groups. The efficiencies are still in the 3–4% range but much research is being conducted in this field.

meaning to date that HC solar cells are just experimental technology. The schematic of HC solar cell is presented in Fig. 2, adapted from Tyagi et al [5].

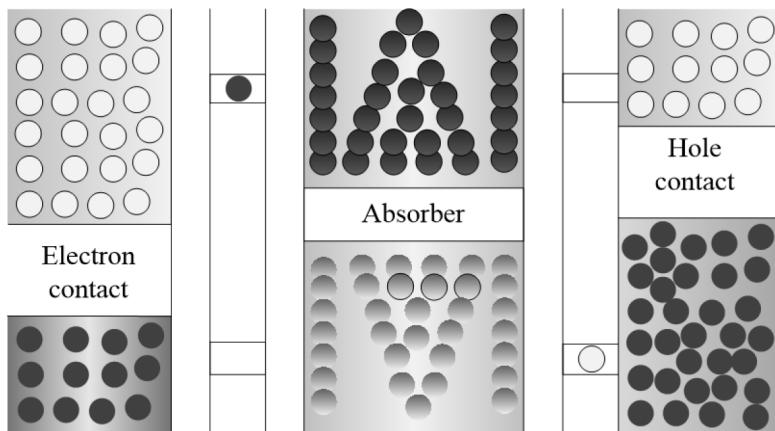


Figure 2 - HC schematic

3 Nanofluids

Nanofluids can be tailored to provide superior optical and thermo-physical properties and thus have increasingly attracted attention for use in solar thermal applications. Up to a 10% increase in the efficiency has been reported through the use of nanofluids compared to conventional collectors [7].

As a colloidal mixture made of a base fluid and a nanoparticle, nanofluid is a new generation of heat transfer fluids becoming a high potential fluid in heat transfer applications due to enhanced thermal conductivity [12]. Nanofluids have great potential in a wide range of fields, and their concept is extended by use of PCMs, going well beyond simply increasing the thermal conductivity of a fluid.

Unlike micron-sized suspensions, nanofluids, known as the suspension of nano-sized solid particles in a liquid, were found to form stable systems with next to no settling under static conditions [13]. Even at small concentrations of nanoparticles ($\sim 1\%$ mass fraction) these stable suspensions anomalously increase the thermal conductivity compared to that of the base fluid. In some cases increases in specific heat capacity have been observed [14].

Taylor in his paper (Taylor et al., 2013) gave nanofluid possible advantages over traditional heat transfer fluids:

1. Due to the incredibly small size of the particles they are essentially fluidized. Allowing them to pass through pumps, micro-channels and piping without any adverse effects.
2. Nanoparticles act as the absorption medium allowing the nanofluid to directly absorb solar energy.
3. Optically selective, allowing for high absorption in the solar range while obtaining low emittance in the infrared. Allowing for a volumetric receiver instead of a selective surface system, which is favorable as selective surfaces have a poorer temperature profile resulting in higher emissive losses.
4. Enhancement of efficiency and uniformity of receiver temperature is possible by tuning nanoparticle size and concentration.
5. Enhanced heat transfer may result in improved receiver performance.
6. Absorption efficiency can be altered by tuning the size, shape and concentration to suit conditions.

The main step in experimental studies with nanofluids is their preparation [12]. Nanofluids are produced by dispersing nanometer-scale solid particles into base liquids such as water, ethylene-glycol (EG), oils, etc. The major problem in synthesis of nanofluids is agglomeration. The delicate preparation of a nanofluid is important because nanofluids need special requirements such as an even suspension, stable suspension, low agglomeration of particles, and no chemical change of the fluid.

3.1 Classification of nanofluids

Nanofluids can be normally classified into two categories: metallic and non-metallic nanofluids. The third category is hybrid nanofluids [15].

Metallic nanofluids refer to those containing metallic nanoparticles (Cu, Al, Zn, Ni, Si, Fe, Ti, Au and Ag), while nanofluids containing non-metallic nanoparticles such as aluminium oxide (Al_2O_3), copper oxide (CuO) and silicon carbide (SiC , ZnO, TiO_2) are considered as non-metallic nanofluids, semiconductors (TiO_2), Carbon Nanotubes and composites materials such as nanoparticles core polymer shell composites.

A single material does not possess all the favorable characteristics required for a particular purpose. It may have either good thermal properties or good rheological properties. In many practical applications it is required to trade-off between several properties, and that is where hybrid nanofluids come, exhibiting remarkable physicochemical properties that do not exist in the individual components.

In addition, new materials and structure are attractive for use in nanofluids where the particle liquid interface is doped with various molecules.

3.2 Types of nanofluids

Mainly two techniques are used to produce nanofluids. One-step technique combines the production of nanoparticles and dispersion of nanoparticles in the base fluid into a single step, and this technique have some variations. The two-step method is extensively used in the synthesis of nanofluids considering the available commercial nanopowders supplied by several companies. In this method, nanoparticles are first produced and then dispersed in the base fluids. Based upon the preparation methods, there are different types of nanofluids:

- Alumina nanofluids;
- Aluminum nitride nanofluids;
- Zinc oxide nanofluids;
- Titanium dioxide nanofluids;
- Silicon dioxide nanofluids;
- Iron oxide nanofluids;
- Copper nanofluids;
- Carbon nanofluids;
- Gold and silver nanofluids;
- Graphene nanofluids;
- Hybrid nanofluids.

3.3 Characterization of nanofluids

The nanofluids are characterized by the following techniques: SEM, TEM, XRD, FT-IR, DLS, TGA and zeta potential analysis [12].

SEM analysis are carried out to study the microstructure and morphology of nanoparticles or nanostructured materials. TEM is like SEM, but with much higher resolution. XRD images are taken to identify and study the crystal structure of nanoparticles. FT-IR spectroscopy is done to study the surface chemistry of solid particles and solid or liquid particles. DLS analysis is performed to estimate the average disperses size of nanoparticles in the base liquid media and TGA is performed to study the influence of heating and melting on the thermal stabilities of nanoparticles. Zeta potential value is related to the stability of nanoparticle dispersion in base fluid.

Review of characterization studies reveals that the important information like nanoparticle size, shape, chemical bonds, distribution and stability are found from characterization techniques.

3.4 Nanofluids properties

The properties of nanofluids are mainly based on five parameters: thermo fluids, heat transfer, particles, colloid and lubrication.

Thermo fluid property includes temperature, viscosity, density, specific heat and enthalpy.

Based on the heat transfer are thermal conductivity, heat capacity, Prandtl number and pressure drop.

The parameters based on particles are size, shape, BET (Surface area analysis) and crystalline phase.

Based on the colloidal properties are suspension stability, Zeta potential and pH.

The final properties based on lubrication are viscosity, viscosity index, friction coefficient, wear rate and extreme pressure.

The physical properties of nanofluids are quite different from the base fluid, and density, specific heat and viscosity are also changed which enhance the heat transfer coefficient exceeding the thermal conductivity enhancement results as reported in some experimental studies.

4 Nanomaterial and nanofluid applications in BISTS

Nanotubes can potentially replace indium tin-oxide in solar cells as a transparent conductive film in solar cells to allow light to pass to the active layers and generate photocurrent [16]. CNTs in organic solar cells help reduce energy loss and increase resistance to photooxidation. Germanium CNT diode can be fabricated and it exploits the photovoltaic effect. Photovoltaic technologies may incorporate CNT-Silicon hetero junctions to leverage efficient multiple-excitation generation at p-n junctions formed within individual CNTs.

The inclusion of nanoscale components in PV cells (BIPV or PV/T) is a way to reduce some limitations. Firstly, the ability to control the energy bandgap provides flexibility and interchangeability and secondly, nanostructured materials enhance the effective optical path and significantly decrease the probability of charge recombination.

The use of nanocrystal QDs, which are nanoparticles usually made of direct bandgap semiconductors, lead to thin film solar cells based on a silicon or conductive transparent oxide (CTO), like indium-tin-oxide (ITO), substrate with a coating of nanocrystals [8]. Quantum dots are efficient light emitters because they emit multiple electrons per solar photon, with different absorption and emission spectra depending on the particle size, thus notably raising the theoretical efficiency limit by adapting to the incoming light spectrum.

Initially, the nanofluid applications in solar collectors and water heaters are investigated from the efficiency, economic and environmental points of view. The experimental analysis of thermal conductivity done by some authors, and optical properties of nanofluids are also reviewed. The reason is that these parameters show the capability of the nanofluid to work as an enhanced HTF under high temperature. Sani et al. [17] reported the optical characterization of single-wall carbon nanohorn (SWCNH) nanoparticles for solar energy application. The result shows that carbon nanohorn-based nanofluids can be useful for increasing the efficiency and compactness of thermal solar devices.

Some authors carried out the investigation of nanofluids in the flat-plate collector for low-temperature applications and they found that a nanofluid-based solar collector is more efficient than a conventional solar collector [17]. Low-temperature solar collectors mainly include flat-plate collectors where the operational temperature is below 100°C. In this section, the review of flat-plate solar collectors using a nanofluid as the heat transfer medium has been carried out. It is found that different nanofluids significantly increase the collector's efficiency under non concentrated radiation.

5 Conclusion

Nanotechnology has brought new opportunities for the development of nanoelectronic devices for solar cell applications. All these materials (nanomaterials and nanofluids) have received considerable attention over the last decade as very attractive materials in a number of applications. They represent an innovative solution that can contribute to the improvement of the energy performance of buildings.

Nanofluids have been utilized to improve the efficiency of several solar thermal applications. But the most important challenge in front of the scientist is the cost of nanoparticles, their synthesis and instability and agglomeration problem. These problems need to be resolved in the coming future with improvement in nanotechnology.

All these materials (nanomaterials and nanofluids) have predictable applications in buildings for effective use of solar energy, but many more applications are yet to be discovered.

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