Energy Storage Using Thermal Processes and Nanotubes

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1. Theme description

Since 1970, the science had tried to find a solution at the energy crisis, developing new method to use and storage renewable energy[1].

The United States Department of Energy has expected that the world's energy consumption will be increased by 20% and that overuse fossil fuels will have a hard impact on climate[2].

The hardest current global challenge is to use the renewable energy rather than fossil fuels, improving the storage energy efficiency[3].

One of the most interesting technologies in the energy storage and conversion is the nanostructured materials for their mechanical and electrical properties[4].

Carbon nanotubes (CNTs) are a kind of nanostructured material with very good electrical and mechanical properties thanks to their dimension and surface properties. Carbon nanotubes were discovered in 1991 as a minor byproduct of fullerene synthesis[5]. The research into CNTs has increased, reducing significantly the cost of this technology and improving the processability and scalability[6]. Nanotubes discovered are of two types: single-wall and multiwall.

In the following, an overview the thermal processes to store energy, in particular the using of Carbon nanotubes in energy field (with a description of this technology and a presentation of the major results obtained by CNTs) are reported.

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[1]https://www.history.com/topics/energy-crisis
[2]Shukla, A. K. S. S., &Vijayamohanan, K. (2000). Electrochemical supercapacitors: En- ergy storage beyond batteries. Current Science, 79.
[3]Arico, A. S., et al. (2005). Nanostructured materials for advanced energy conversion and storage devices. Nat Mater, 4(5), 366-377.
[4] Chung, J., et al. (2004). Toward Large-Scale Integration of Carbon Nanotubes. Lang- muir, 20(8), 3011-3017.
[5]Lijima, S. Nature 1991, 354, 56-57.
[6] Sherman, L. M. (2007). Carbon Nanotubes Lots of Potential--If the Price is Right. 01/05/12]; Available from:, www.ptonline.com/articles/carbon-nanotubes-lots-of-po- tentialif-the-price-is-right.

2. Store energy

Solar and wind are intermittent energy sources, so it isn't possible to use that energy to the need. In order to overcome this disadvantage, this kind of energy needs to be stored in a form of intermediate energy (compression, chemical, thermal, potential, etc.) and then converted into electricity during peak demand[7].

Below are showed the most used methods to store energy.

Pumped Hydroelectric Storage (PHES)

Transfer pumping stations are used to pump and expand water between an upper and an artificially created lower reservoir. The efficiency of this system is around 75%.[8]

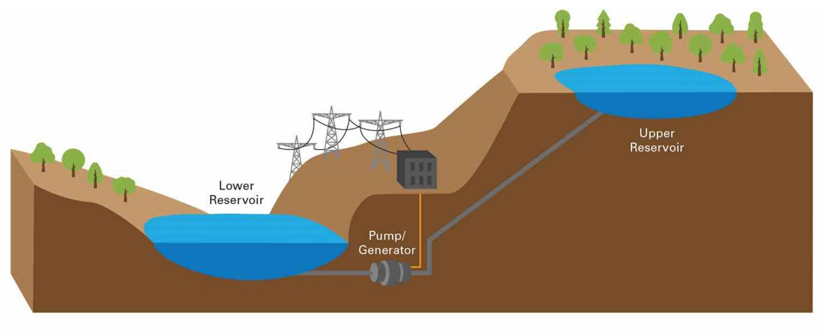

Figure 1. PHES example.

Compressed Air Energy Storage (CAES)

CAES is a hybrid storage and energy production system. It is based on gas turbine and therefore using fuel. So, the air is compressed (stored energy) and then mixed with fuel for combustion. The air is stored at high pressure (40-70bar) in underground caverns.

Electrochemical Batteries

This system used batteries with a reversible electrochemical reaction to store electric energy. This technology is specially used for high power stationary applications (such as sodium-sulfur batteries in Japan)[9].

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[7] https://ac.els-cdn.com/S1876610213011922/1-s2.0-S1876610213011922-main.pdf?_tid=a71a98f3-1d35-4584-a9f3-8664c0e8a486&acdnat=1525855044_d2061ed89f5382b89fb8739d2aaa849b

[8] http://energystorage.org/energy-storage/technologies/pumped-hydroelectric-storage

[9] Odru P. Colloque Hautes températures pour le stockage électrique – Contextegénéral, Ecole des Mines Paris 4 Juillet 2012

Hydrogen Vector

The electrical energy produced by renewable source can be stored in chemical form using the hydrogen vector. It is used as fuel or for electricity production by fuel cells. The storage requires highly compressed hydrogen gas (350 bar) or liquid hydrogen.

Molten Salts

The solar energy collected by concentrated solar power can be stored in insulated container using molten salts fluid vector[10]. This technology stocks molten salts at high temperature and uses a steam turbine to produce electrical energy during peak demand.

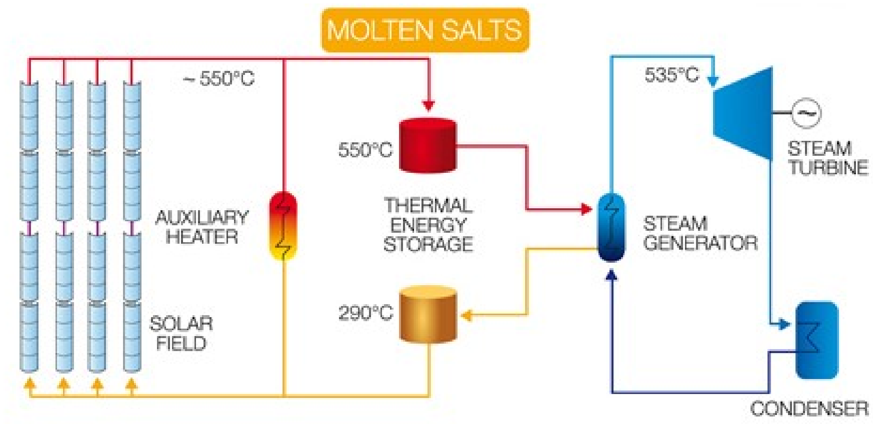

Figure 2. Solar Central with Molten Salts.

3. Carbon Nanotubes Production

There are four kinds of processes for the growth of CNTs[11]:

- Laser ablation;
- Arc-discharge;
- High pressure carbon monoxide disproportionation (HiPCO);
- Chemical Vapor Deposition (CVD) method.

[10]http://www.archimedesolarenergy.it/it_molten_salt_vs_oil.htm

[11] Carbon Nanotubes for Energy applications, Dennis Antiohos, Mark Romano, Jun Chen, Joselito M. Razal, INTECH, http://dx.doi.org/10.5772/51784

Laser ablation

The Laser ablation method involves the condensation of carbon atoms generated from the evaporation of carbon sources. The high temperature range is 3000-4000 °C[12]. This method focuses a CO_2 laser (in continuous wave or in pulsed mode) on a rotating carbon target, for a period time, producing high quality of CNTs with a high degree of graphitization[13].

Arch-discharge

The Arch-discharge method involves the condensation of carbon atoms generated from the evaporation of carbon sources too. The high temperature range is 3000-4000 °C. This method induces various gases (such as Helium or Hydrogen) into plasma, using large currents generated at a carbon anode and cathode. At the end of this process, the evaporation of carbon atoms produces very high quality of CNTs in MWNTs and SWNTs form (multi-walled nanotubes and single-walled nanotubes)[14].

HiPCO

The high-pressure carbon monoxide disproportionation process uses clusters of Fe particles as catalyst to produce very high quality of CNTs in SWNT form[15]. Thermal decomposition of iron pentacarbonyl forms catalyst. The $Fe(CO)_5$ decomposes into atoms,condensing into larger clusters at the end (during the heating phase)[16].

CVD method

Chemical vapor composition method uses a furnace, carbon source, catalyst method, a carrier gas, a conditioning gas and a collection device. The reacting material is taken by the carrier gas onto the substrate where CNT growth[17]. This process has the advantage to directly deposit the CNTs onto the substrate (the other process can't do this).

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[12]Meyyappan, M. (2005). Carbon Nanotubes: Science & Applications. Boca Raton: CRC Press

[13]Yuge, R., et al. (2012). Characterization and field emission properties of multi-walled carbon nanotubes with fine crystallinity prepared by CO2 laser ablation. Applied Sur- face Science

[14] Cai, X., Cong, H., & Liu, C. (2012). Synthesis of vertically-aligned carbon nanotubes without a catalyst by hydrogen arc discharge. Carbon, 50(8), 2726-2730

[15]Zhihua, P, et al. (2008). Investigation of the microwave absorbing mechanisms of HiPco carbon nanotubes. Physica E: Low-dimensional Systems and Nanostructures, 40(7), 2400-2405

[16] Nikolaev, P. (2004). Gas-phase production of single-walled carbon nanotubes from carbon monoxide: A review of the HiPco process. Journal of Nanoscience and Nanotech- nology, 307-316

[17]Meyyappan, M. (2005). Carbon Nanotubes: Science & Applications. Boca Raton: CRC Press.

4. Carbon Nanotubes Features

Carbon nanotubes are allotropes of carbon with a cylindrical nanostructure. The CNT name derives from its size, since the diameter is one the order of nanometers and its length can be up to 18 centimeters.

As mentioned previously, the CNTs can have two forms:

- SWNTs (single-walled nanotubes);
- MWNTs (multi-walled nanotubes).

SWNTs

SWNTs have been studied extensively as a hybrid energy material and supercapacitor[18]. The structure of a SWNTis showed in Figure 1.

It has very good conductive and thermal properties, where a potential current carrying capacity of $10^9 A/cm^2$and the thermal conductivity can exceed 6000 $Wm^{-1}K^{-1}$[19].

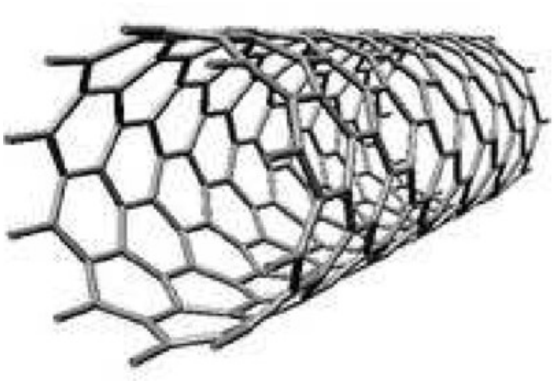

Figure 3. SWNTs.

[18] Wang, G., Zhang, L., & Zhang, J. (2012). A review of electrode materials for electro- chemical supercapacitors. Chemical Society Reviews, 797-828

[19] Dai, L. (2006). Carbon Nanotechnology. Amsterdam: Elsevier

MWNTs

MWNTs, like SWNTs, is studied extensively as electrode materials for supercapacitors. It is more easily synthesized on much larger scales then SWNTs, making them more useful for commercial application.

The concentric structure of MWNTs is showed in figure 2.

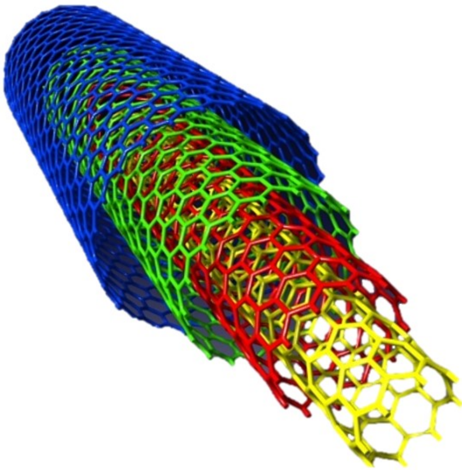

Figure 4. MWNTs structure.

5. Carbon Nanotubes for heat battery

CNTs is an innovative approach to storing solar energy, allowing to be used as needed[20]. The principle would be storage the sun's heat in chemical form rather than converting it to electricity (or using heavily insulated container).

The advantage of this method is that the chemical material can be stored for a long time, without losing its stored energy.

Before the CNTs, the problem of using chemical material was that the conversion and storage degraded within a few cycles. The CNTs is a new chemical system, less expensive, with at high efficiency and capability of solar energy storage[21].

CNTs allows to control the quantity of energy storage and the period of time needed before the release. Using a catalyst (small temperature change, a flash of light, etc.), CNTs can quickly release the stored energy, like a conventional battery. It is possible thanks to the molecular structure that can changes when exposed to sunlight, remaining stable in that form.

This new method combines energy harvesting and storage in one single step, simplifying the whole process. The limitation is that to produce electricity it is

[20] https://www.sciencedaily.com/releases/2011/07/110713121301.htm

[21] Storage of Sun's Heat By Using Modified Carbon Nanotubes, BalasaiSabarinath, Pradeep Elangovan, 978-1-4673-0074-21111$26.00 @2011 IEEE

necessary another conversion step, using thermoelectric devices or producing steam to use in a generator.

An energy barrier is used to control thermal storage, as it separates the two stable states of the molecules:

- If the barrier will be too high, it is not possible to easily release the energy stored;
- If the barrier will be too low, it is not possible to store energy for a long time.

6. Conclusion

Thermal converters have the potential to increase the efficiency of current energy conversion systems. Energy storage also has a key role to supply a solution to the energy problem. Energy must be efficiently stored, when it is in excess, and released at a time of high demand when we talk about renewable sources that are not load-following.

CNT is one of the most actual promising technology to stock and release energy: CNTs allows to control the quantity of energy storage and the period of time needed before the release, doesn’t need container to stock energy and it storages the sun’s heat in chemical form rather than converting it to electricity.