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10th June 2017

9th June 2017
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To Improve the Thermal Properties of Mineral Wool by Adding Aerogel

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Global warming and its effects on climate change are causing environmental and social changes. Natural disasters occur more frequently and are more powerful. Rising sea levels force entire island communities to relocate. Currently, many countries are investing in various endeavors to solve the problems caused by global warming and climate change. One approach to achieving the goals of energy conservation and CO2 reduction in the building and industry sector is to use good thermal insulating materials in processing facilities and piping systems. To reduce the cost of fuel and heat loss from the pipe surfaces, insulation needs to cover pipers when high temperature fluids are transported through them. While possessing a wide range of applications, mineral wool has been used industrially as a thermal insulator due to its low heat conductivity as well as good thermal and flame resistant properties. It has been shown not only to reduce the noise during transport through pipelines but also to provide excellent thermal insulation for pipelines.

Subsequently, aerogel is regarded as one of the most promising high performance thermal insulation materials today, but only limited commercial products are available thus far due to cost and reliability factors. In efforts to create a thermal insulator with superior properties compared to traditional materials, this study was conducted to combine the material properties of silica aerogel and mineral wool. The purpose of this study is to develop a manufacturing process by adding silica aerogel to mineral wool to form a mineral-wool composite. The thermal performance of the mineral wool-aerogel composite was then analyzed in an investigation to meet the requirements for industrial applications. In this study, mineral wool-aerogel composites, synthesized at varying mineral wool/TEOS weight ratios, were prepared at room temperature and completed with an ambient pressure drying method. Nitrogen adsorption analysis and FTIR spectroscopy were employed to investigate the physical and chemical properties of the composites. Finally, the thermal conductivity of composites was measured to evaluate their thermal performance.

The experimental results indicated that silica aerogel can be successfully produced in mineral wool using an ambient pressure drying process. Furthermore, the mineral wool-aerogel composite demonstrated itself as a better thermal insulator than mineral wool. As aerogel was mixed in with mineral wool, the measured thermal conductivity of the mineral wool-aerogel composite can be reduced from 0.071 to 0.055 W/m*K. In terms of manufacturing feasibility, the experimental process required about twelve hours, but this time and process can be effectively shortened to enable mass production. In conclusion, mineral wool-aerogel composites show promise in industry applications due to possessing properties of both materials. Improvements to the manufacturing process will enable it to become a commercial product.

Figure 1: Aerogel powder and mineral wool-aerogel composite

Figure 2: Thermal conductivity and density versus aerogel weight fraction
New Emerging Technology of Dense-Array Concentrator Photovoltaic System

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For cost effectiveness, non-imaging focusing technologies have widely been deployed in the application of concentrator photovoltaic (CPV) system, which can be categorized based on the nature of sun-tracking methods: on-axis tracking design and off-axis tracking design. The merits of adopting non-imaging optics into primary concentrator with segmented mirror facets are many and we just mentioned a few points here. Firstly, the non-imaging optical device provides a great flexibility to tailor the focused image in different shape and dimension based on the receiver design. Secondly, the multi-faceted design of non-imaging solar concentrator allows a flexibility to adjust the focal distance. Thirdly, non-imaging optical device can form uniform illumination that is highly required by CPV system. Inspired by the aforementioned advantages, we have invented a computer generated geometry namely non-imaging dish concentrator (NIDC) that is constituted of many flat facet mirrors with the purpose of producing uniform focusing spot. Hence, dense-array concentrator photovoltaic (DACPV) receiver can be placed at the target to convert the concentrated sunlight into electricity. The assembling of DACPV module requires minimum gap between solar cells to prevent the concentrated sunlight illuminated on physical area without active solar cell material. The interconnection between solar cells and the build-in bus bars on the surface of CPV cell have inevitably increased non-active area of the receiver. It is impossible to achieve 100% packing factor of DACPV module.

Packing factor is defined as the ratio of usable active area of solar cells to the total illumination area on the incident surface. Low packing factor affects the power conversion efficiency of DACPV system given that some of concentrated sunlight fallen on non-active area of the receiver. Increasing the percentage of incident rays onto the active area of solar cells is plausible by introducing secondary concentrator in which the solar cell is directly attached to its exit aperture. The secondary concentrator acts as optical funnel to guide the concentrated sunlight from primary concentrator to solar cells. There are many advantages of introducing secondary concentrator to the DACPV system. Firstly, the secondary concentrator can provide more space for the interconnection between solar cells that allow more flexibility in the ways of connecting solar cells in both series and parallel to minimize the current mismatch. Secondly, each CPV cell can have individual by-pass diode for protecting the cell and improving the fill factor of the CPV system. Thirdly, the solar concentration ratio of the whole concentrator assembly can significantly be multiplied and hence reducing the usage of solar cells. In our design, an array of 3-D dielectric filled compound parabolic concentrators (CCPCs) was used as secondary concentrator with each of them coupled to a single CPV cell to form a good optical combination with NIDC. The important benefit of DACPV system as compared to current Fresnel type of CPV system is to allow recollection of waste heat in the form of hot water at the temperature of 60-70°C that can be used for hot water shower, producing desalinated water or powering adsorption chiller.

Prototype of non-imaging dish solar concentrator with dense-array concentrator photovoltaic receiver fixed at the target.
“Heat from Cold”: A New Adsorptive Cycle for Upgrading the Ambient Heat

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Any lack of equilibrium between a system and the environment can be used to produce work. The maximal work is determined by the second law of thermodynamics (SLT) as \( W = Q \left( 1 - \frac{T_{am}}{T_H} \right) \), where \( Q \) is the amount of heat supplied from a thermostat at high temperature \( T_H \), \( T_{am} \) is the reference ambient temperature. At present, a majority of thermodynamic cycles of heat engines are high-temperature cycles that are realized in steam, internal combustion and diesel engines, steam and gas turbines, etc. These cycles are mainly based on burning of organic fuel that may result in dramatic increasing of CO\(_2\) emissions and global warming.

Renewable energy sources (the sun, wind, ambient heat – natural water basins, soil, air, etc) have significantly lower temperature than that achieved by burning fossil fuels which open a niche for applying adsorption technologies for heat transformation. By now, several adsorptive chillers/heat pumps have already appeared in the market. These units are driven by a temperature difference between the ambient (280-310K) and an external heat source (330-450K), the latter being used for adsorbent heating and regeneration.

Afterwards, this work can be used to upgrade the temperature of heat taken from the water reservoir up to a level \( T_H \) sufficient for heating, thus gaining commercial value. So, the heat transformation can be conventionally considered as two reversible Carnot cycles of a heat engine and a heat pump (Fig. 1).

The simplest version of the new adsorptive cycle operates between three thermostats at TL, TM and TH (Fig. 1) and consists of two isosters and two isotherms (Fig. 2a). The main feature of this cycle is that regeneration of adsorbent is performed by dropping the vapour pressure over adsorbent at its relatively low temperature TM (stage 4-1 in Fig. 2a). This pressure drop is ensured exclusively by the low ambient temperature, and does not need any supply of heat that has commercial value. Since the useful heat is deemed to be obtained by means of a low ambient temperature, the new cycle is called “Heat from Cold” (HeCol). More details of the HeCol cycle and its first realization can be found elsewhere [1-3]. The new cycle works better at lower ambient temperature TL and, hence, may be interesting for countries with a cold climate which occupies the huge territory of the World (see the dark blue zones on Fig. 2b), and especially for the Arctic.

Potential implementation of the new cycle to implicate even a little part of the environment heat that is enormous and free, to heat production could terrifically change the structure of modern energy sector and decrease unsettling dependence of the human society on fossil fuels.
A Novel Design of Portable Photovoltaic Direct-Driven Refrigerator

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Due to the growing refrigeration demand in people’s outdoor activities under the off-grid conditions, the movable/instant refrigeration has become increasingly important. Considering that cooling demand shows positive correlation with the solar irradiation intensity, higher solar irradiation can supply more power to drive the refrigeration cycle, so the photovoltaic refrigeration is a worthy solution. On this basis, a novel form design of portable photovoltaic direct-driven refrigerator is proposed and the working prototype has been constructed in University of Science and Technology of China, as shown in Fig. 1. The system includes two main parts: photovoltaic power generation system and DC refrigerator. Unlike previous portable refrigeration system, there are no buffer batteries placed in the system, avoiding almost half of weight and cutting down the majority of the total investment, which greatly enhanced the mobility and economy of the system.

The PV module consisting of polysilicon solar cells, directly connects to the compressor controller. The refrigerator applied in the project is modified from a small conventional one, by replacing the AC compressor with a DC one in which the rotate speed could be adjusted by changing the speed control signal transferred to the compressor controller. The speed control signal is given by irradiation intensity sensor and voltage signal amplifier. The voltage of the signal increases with the irradiation intensity, and the input power of compressor grows with the rotating speed. As a result, efficient energy utilization is realized, and the negative effect of irradiation fluctuation, which causes the frequent on/off of the compressor, can be reduced. The speed control signal and thermostat are connected in series before linking to the controller. The system can work in two modes determined by the working state of the thermostat. When the thermostat is always in the operating state, the system works in a continuously cooling mode. In this mode, the transformation between solar energy and cool energy storied in water can be maximized. When set at a fixed temperature point, system works in an intermittent mode to keep internal environment at a constant temperature. In both modes, compressor speed is controlled in accordance with the irradiation intensity. In addition, a small DC fan is placed in the cabinet to enhance the heat convection, benefit for fast cooling in the outdoor scene.

The experimental results verified that the system shows satisfactory performance in clear days. The performance of the system under constant frequency operation and variable frequency control strategy has been compared. The final refrigeration quantities of the two working strategies are $8.82 \times 10^5$ J and $7.18 \times 10^5$ J respectively. The value can be improved by 22.8% by introducing variable frequency control strategy compared with constant frequency operation. While the net coefficient of performance (COP) in variable frequency control strategy is 16.6% lower than that in constant frequency operation, which is caused by the rise of pressure ratio of the compressor. The usage of internal fan has a significant influence on the overall performance of the system. It took 4.40 hours to cool 4.4 liters of water from 21°C to 5°C without internal fan, and the time can be shorten to 2.67 h with the assistance of fan.

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Figure 1: Schematic diagram and working prototype
Energy usage, economical and environmental issues are becoming a focal point for both end users and the public at large. Current trends towards privatisation and an open market approach for utility companies has created a new kind of energy market whereby the period of energy usage and type of energy used is becoming the main criteria for price structuring rather than overall energy consumption. Hence, current building services must be designed to provide sufficient flexibility for load shifting and energy usage control in order to achieve the most economical operation. A Thermal Energy Storage (TES) technique whereby "Storing High or Low Temperature energy for later use in order to bridge the time gap between energy availability and energy use" can be considered as a useful tool to achieve this aim.

Phase Change Materials (PCM) between +4°C and +90°C ranges overcomes the water disadvantages by combining the latent and sensible energy storage capacities into a single storage unit and therefore offer designers new horizons and practical application options. PCM latent heat cool energy storage can be provided by utilising conventional water chillers for new and retrofit applications without the need for any modifications as well as having the possibility of free cooling together with economical benefits for many heating and cooling applications.

Typical PCM applications are illustrated in Figure 1.

For Passive Cooling applications, one may enable the charging process to take place by means of free cooling, i.e. without running the chillers and as a result becomes a very economical and environmentally friendly system.

It opens new opportunities to explore heat balance for the existing and new systems, which could offer significant overall system efficiency improvements. Typical passive cooling applications are illustrated in Figure 2.

Phase Change Materials (PCM) solutions utilise free ambient cooling, conventional chilled water temperature ranges for both the charging and discharging sides of the system. Hence, they can be applied to any new or retrofit application with minimal technical and economical impacts. Furthermore, the possibility of Free Cooling Cycle TES system offers new horizons for designers to control the energy balance to match the load and electricity demand/consumption of the system as a whole. The task for designers is to explore all available technologies towards achieving improved efficiency regardless of which refrigerant is used and apply where and when possible diversification technologies in order to minimise the overall CO2 emission related to energy usage. A carefully balanced PCM energy storage may be the answer for many of the cooling applications for an Environmentally Friendly and Economical alternative.
MCI Technologies which is WINCO Technologies’ research and development laboratory, manages the PCM group within the consortium led by VALEO as part of the PAGE project (electric vehicle: optimized thermal and energy management)

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Project summary

Background
The use of electric vehicles still remains marginal due primarily to their autonomy, which is too low. A significant autonomy increase can be envisaged by developing a related system for cabin heating and for the thermal management of the electric battery, thus avoiding using a part of the electric battery energy.

Solutions
The VEGETTO project aims to develop two major technological solutions to improve these defaults that hamper the development of the electric vehicle:

• One of the solutions is to implement within the electric battery a system of mixed regulation (passive and active) which will limit thermal heating during the recharge and the discharge of the electrical energy.
• The alternative is the development of a heat accumulator (active system) dedicated to the cabin heating.

PCM Technology
These two solutions are based on the use of solid-liquid type phase change materials (PCM) which have the property of absorbing high quantities of (latent) heat for a reduced mass and which make it possible to stabilize at an almost constant temperature the system in which these PCM are inserted. These objectives include the development of low melting point (25°C) PCM to regulate the electric battery temperature and high melting point (70°C) PCM to store the heat and to release it for the cabin heating. The research will focus on the physicochemical properties of the developed PCM, the manufacturing of prototypes, the dynamic study of a thermo-controlled battery integrating PCM and the optimization of a thermal accumulator during charging and discharging.

The development of many fusion points for temperature-controlled plastics offer many opportunities in various fields:

• Food packaging: keeping nomadic packaging (transport boxes, polyamine and melamine tableware) warm or cool.
• Bedding: cooling effect textiles (linings for duvets and pillows, synthetic or natural fibers by impregnation)
• Mechanics: improvement of seals’ lifespan during metal parts heating by friction or fluid conduction.
• Aeraulic industry: energy storage in heat exchangers for ventilation systems.
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