Maejo Int. J. Sci. Technol. **2017**, *11*(02), 148-157

Maejo International
Journal of Science and Technology

ISSN 1905-7873
Available online at www.mijst.mju.ac.th

Full Paper

A new prototype of thermoelectric egg incubator integrated with thermal energy storage and photovoltaic panels

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Received: 16 August 2016 / Accepted: 20 July 2017/ Published: 25 July 2017

Abstract: The purpose of this study is to develop a thermoelectric egg incubator (TEI) integrated with a thermal energy storage (TES) system, using electricity from photovoltaic (PV) cells in order to operate without on-grid electricity. The TEI was constructed with the same dimensions as a commercial egg incubator (CEI), which was made to the required dimensions for hatching 24 eggs per period of 21 days. The TEI was designed with 2 operating modes of heat sources: a thermoelectric (TE) module used for daytime operation and a TES containing phase-change materials (PCM) which supplied heat to the TEI for nighttime operation. The PV panels were designed to be the primary energy source for generating 360 W of electricity, which was supplied to heat sources of TEI according to the energy load for providing fertile chicken eggs (24 eggs/hatching). The incubating temperature and relative humidity (RH) inside the TEI-TES were controlled under optimum environmental conditions for hatching (36-39°C and 60-80% RH) to stimulate embryonic growth. As a result, the TEI-TES achieved and maintained an optimum incubating temperature in the range of 36.7-38.8^{o}C and the correct RH of 66±0.2 % in the warm weather of Thailand over the incubating period of 21 days. The TEI-TES was able to maintain optimum environmental conditions for chicken-egg hatching, and its performance was comparable to that of the CEI. The working mechanisms of the TE module and TES are also discussed. The results show that the TEI-TES with PV panels as the primary energy source is suitable for use in remote areas which have no on-grid electricity supply.

Keywords: egg incubator, thermoelectrics, hatching, thermal energy storage

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Maejo Int. J. Sci. Technol. **2017**, *11*(02), 148-157

INTRODUCTION

New technologies play an important role in modern agricultural practice. In the commercial production of poultry products such as meat and eggs, a guaranteed sufficient supply of brood chicks is essential. This cannot be achieved by natural incubation by means of broody hens sitting on clutches of eggs. The development of a new technology for a more efficient hatching of fertile eggs is important. The artificial incubator is an important technology for use as an alternative approach to the hatching of fertile chicken eggs without the involvement of broody hens. Egg incubators, which are widely used in the industry, must be well controlled to provide a hatching process under optimum environmental conditions (temperature, egg turning and humidity) to stimulate embryonic growth until hatching [1]. The temperature and relative humidity (RH) inside the incubator must be controlled to optimum environmental conditions in the temperature range of 36-39°C and RH of 60-80% [1-3]. The incubating temperature is the most crucial factor in incubating efficiency [1, 4]. In the case of the commercial egg incubator (CEI), a heating element is used as a heat source by directly converting electricity to thermal energy. The CEI has been designed in several forms and versions for manual operation and also for fully-automatic and semi-automatic operations [2]. The forced-air egg incubator is one of those approved due to its action of hot-air circulation through the use of an exhaust fan, which provides the necessary stable heat level, suitable moisture level, and the maintenance of appropriate amounts of oxygen inside the incubator [1, 2, 4, 5]. An egg-hatching incubator integrated with a conveyor rotation system has been designed and developed using an automatic controller for the maintenance of temperature and humidity [6]. However, it cannot be used in remote areas not serviced by electricity supply infrastructure. Recently, a photovoltaic (PV)-powered chicken-egg incubator was constructed for use in the rural areas of Serra Leone; nevertheless, a large-capacity battery was required for operating the system for 24 hours [7].

The thermoelectric (TE) technology, which involves the conversion of waste heat into useful electricity, can provide a method of heating and cooling by electricity. TE modules can be used for both power generation and solid-state refrigeration or heat pumps. A TE module has no mechanical moving parts or environmentally harmful fluids like chlorofluorocarbons [8, 9]. The TE systems are gaining an increasing level of attention because of their reliability and environmentally friendly energy conversion technology (heat-pump technology). They are of small size, provide maintenance-free operations, emit no pollutants and are feasible for use in a wide temperature range [8, 10]. TE technology is currently expected to contribute to solving global warming and climate change issues because of its improved total energy efficiency and reduced consumption of fossil fuels. In previous studies, TE modules were successfully initiated as a new heating device to replace the heating element in the CEI, and it was found that egg incubators with TE modules as heat sources exhibit high efficiency, resulting in low electrical fees per hatching period [11, 12].

Thermal energy storage (TES) is very important in many engineering applications. Among the practical problems involved in solar energy systems is the need to increase the reliability of the system by storing any power produced in excess of the energy load. The stored energy can be used whenever needed, such as during the night or on overcast days [13]. Similarly, practical engineering problems arise from the waste-heat recovery system where waste heat availability and utilisation periods are different [14]. A phase-change material (PCM) is a latent-heat storage material used for TES. The PCM can store or release a large amount of heat during the phase change process. TES systems containing PCM in the solid-to-liquid phase have been considered as a potential candidate for solar energy systems. These types of TES systems have a small volume and work in the known melting and solidifying temperature ranges of the PCM [13, 15, 16], which is used in latent heat storage for several applications such as solar energy systems, heat pumps and spacecraft thermal control, as well as for cooling applications in buildings [16].

In previous TE models, the TE module was successfully tested as a new heating device in egg incubators, but it still used electricity from the national grid [11, 12]. Furthermore, a large-capacity battery was required for the PV-powered chicken egg incubator [7]. In order to develop a thermoelectric egg incubator (TEI) that can be operated in rural areas where grid-supplied electricity is not necessarily available or reliable, we have integrated a TE module in a TES and used it as a heat source in the TEI. PV panels are used as the primary power source for the TE module and TES. The TEI is integrated with the TES and PV panels. As far as we know, this is the first time that this design has been used.

In the present study the design of this TEI integrated with the TES (TEI-TES) and PV panels has been developed based on the optimum chicken egg hatching period of 21 days (the usual hatching period of a chicken egg), with optimum temperature and humidity control 24 hours a day. The optimum incubating temperature and % RH of the TEI-TES were investigated, identified and compared with conditions used in a CEI.

MATERIALS AND METHODS

A TEI was constructed with the same dimensions as a CEI, which was 0.35 m wide, 0.35 m long and 0.44 m high, the required dimensions for accommodating the hatching of 24 eggs per period (Figure 1a). The incubating box was made of plywood 10 mm thick. Three-mm-thick polystyrene insulation covered the outer surfaces of the incubating box in order to reduce heat loss. Figure 1b illustrates a TE module (TEC1-12710 model, Thermonamic Electronic Co., P.R. China) with 127 couples. The module was 40 mm long, 40 mm wide and 3.4 mm high. The performance specifications of the module were: 79^{o}C for maximum temperature difference between hot and cold sides of the module (ΔT_{max}), 17.2 V and 10.1 A at maximum voltage; DC current at ΔT_{max}, and 1.27-1.49 Ω for AC resistance. The module was mounted on top of a TEI box as the heat source in place of a heating element, as in the CEI (Figure 1c).

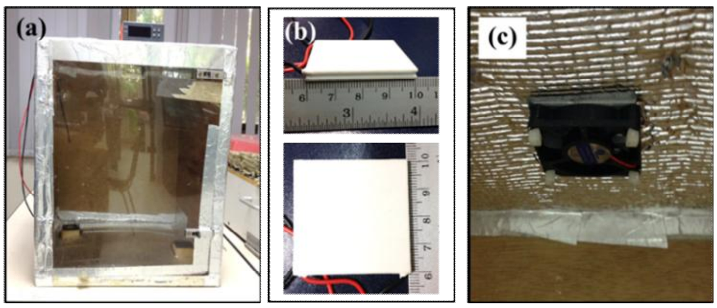

Figure 1. (a) TEI unit; (b) TE module (TEC1-12710); (c) installation of TE module at the top of TEI unit

The TES was designed to provide sufficient heating load for maintaining correct temperature conditions for the chicken eggs during the night [4]. The TES unit was made from stainless steel sheet 1 mm thick with dimensions of 0.35 m (width), 0.35 m (length) and 0.1 m (height). A 1500-W heating element with three parallel circuit lines (each 0.55 m long) was installed inside the TES unit for converting electricity from the PV panels to thermal energy. Two 1 mm-thick stainless steel pipes with an outer diameter of 25.4 mm were also mounted inside the TES unit, as illustrated in Figures 2a and 2b. In the present study paraffin wax was used as PCM, which has a melting point of 70°C, a latent heat of fusion of 173.6 kJ/kg, and a density of 0.790 g/cm^3 at 70°C. Seven-kilograms of the paraffin wax were contained in the TES unit to ensure sufficient thermal energy during the night. Rockwool, 40 mm thick, covered the outer surfaces of the TES unit to prevent heat loss. Then the TES unit was installed at the bottom of the TEI box, as shown in Figure 2c.

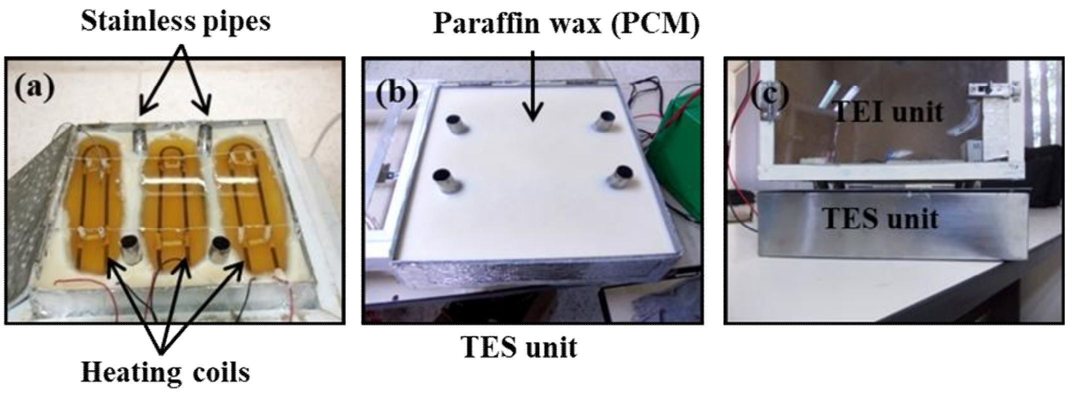

Figure 2. (a) 3 parallel heating elements and 2 stainless pipes inside TES unit; (b) paraffin wax contained in TES unit; (c) mounting TES unit at the bottom of TEI unit

In order to make the TEI operable in rural areas where grid-supplied electricity is not available, three PV panels (polycrystalline Si, 120 Wp, ES20636120, GIN Group, Italy) were used as the primary energy source. The PV panels generated ~360 W of electrical power for the TE module and the heating elements in the TES. Figure 3 presents the TEI apparatus, with the TES and PV panels included, which can operate without on-grid electricity. The overall TEI system (TEI-TES) is composed of several main parts: TE module, TEI unit, TES unit, PV panels and a battery (24 V, 120 Ah). The system is also fitted with a temperature controller, a charger-inverter (Apollo S-120A, Leonic Co., Thailand) and a type-K thermocouple. Air circulation inside the TEI during hatching is assisted by airflow fans. A water tray is placed in the bottom of the TEI to control the humidity in the incubator.

The TEI-TES has two heating modes as shown in Figure 3. When operating in TE mode, the TE module is the heat source during daytime, while during the night it operates in TES mode and heat is derived from the PCM. The two stainless steel pipes mounted inside the TES unit transfer heat from the TES to the TEI via a fan installed at the end of each pipe. The optimum incubation temperature of 38°C inside the TEI-TES is controlled by the temperature controller.

The type-K thermocouple is mounted inside the TES at the centre of the incubating chamber and on both the hot and cold sides of the TE module. A manual 3-way switch turns on the temperature controller at 6 a.m. to operate the TE module and turns it off at 6 p.m. The TES is switched on at 6 p.m. and switched off at 6 a.m. During the day, the PV panels generate DC electricity which is supplied to the TE module at 12 V and 5 A through the charger-inverter and battery. Three 3 PV panels simultaneously supply DC electricity to the heating element circuit for generating thermal energy and melting the paraffin wax when the temperature is higher than its melting point at 70°C inside the TES unit. This means that heat is absorbed inside the TES unit during the day and is discharged to the TEI chamber during the night. Two air vents 10 mm in diameter are installed at the back of the incubator at a height of 50 mm from the bottom of the TEI unit. The oxygen consumption and carbon dioxide concentration inside the incubator are optimised through the air vent during the metabolism period of embryo change.

The performance of the TEI-TES and PV panels were monitored 24 hours a day over 21 days (one chicken-egg hatching period). The temperature and humidity inside the TEI chamber were recorded with a data recorder (AI 210, Wisco, Thailand) connected to a personal computer and a multifunction environment meter (DT-8820, CEM-meter, China).

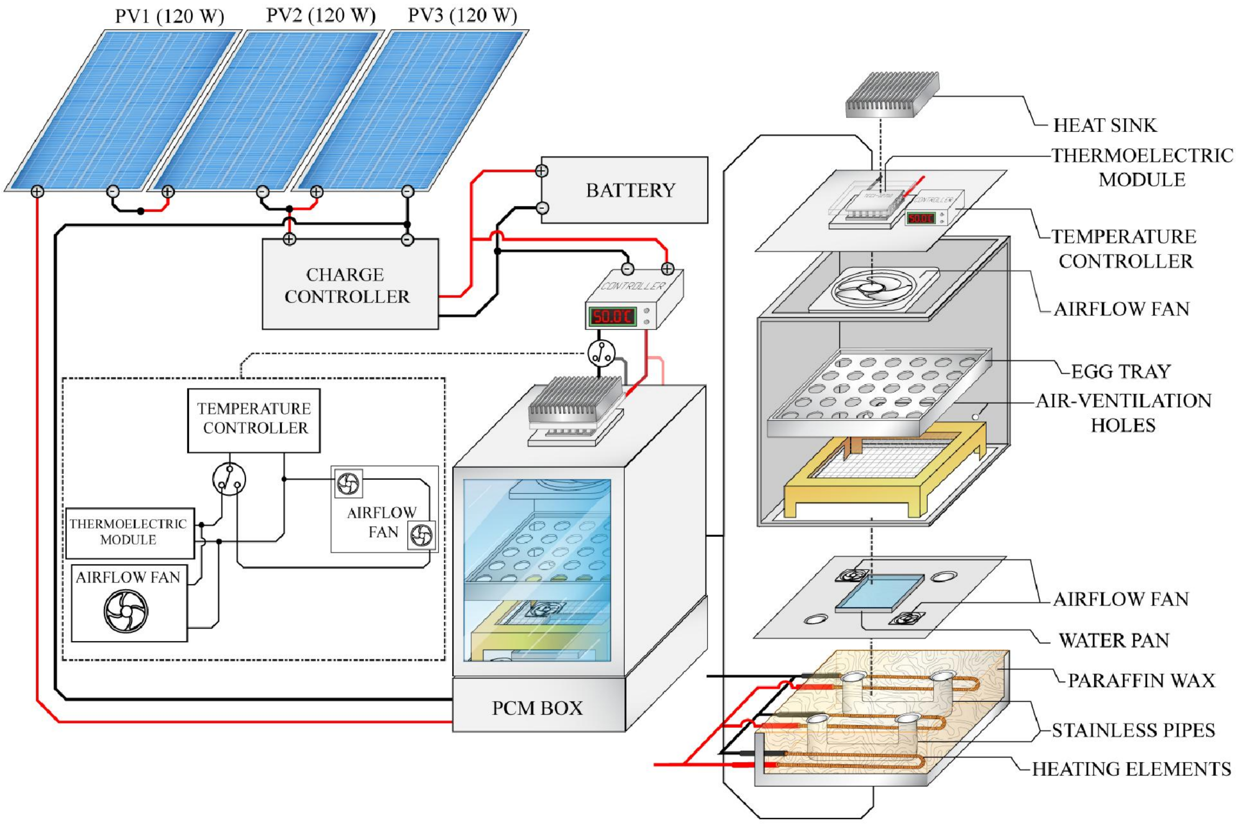

Figure 3. Schematic of the constructed TEI-TES and PV panels

RESULTS AND DISCUSSION

The incubating temperature is an important factor influencing the embryo development and metabolic rate during incubation. In the present study the incubating temperature inside the TEI-TES and CEI was continuously recorded 24 hours per day over 21 days (1 chicken-egg hatching period) in order to maintain the optimum incubating temperature of 36-39^{o}C [1-3]. The incubating temperature inside both the commercial and experimental incubators was controlled by a temperature controller set at 38^{o}C for the whole hatching period. The temperature controller was automatically turned off when the temperature inside of chamber rose above 38^{o}C and was restarted when the inside temperature cooled to 36°C.

Figure 4 presents the incubating temperature profile of the TEI-TES compared with the CEI on the 1st and 2nd days of the incubation period, together with room temperature (RT), TES temperature, and temperatures on both the hot and cold sides of the TE module. On the 1st day of incubation, the TEI-TES and CEI were started at 8 a.m. The RT profile exhibited a dome-like shape, increasing from 26˚C at 8 a.m., reaching the highest temperature of 34.7˚C between 1–4 p.m., and decreasing during the night. Atmospheric conditions (clear skies or overcast, dry weather or raining, cool temperature or hot, etc.) were observed and recorded for their effects on the RT profile. The PV panels produced the DC current which was supplied to the TE module and heating elements inside the TES unit during daytime. The initial temperatures for the TEI-TES and CEI were set at room temperature of 26.7°C. The hot side of the TE module was 42.2°C and the cold side was 31.1°C. The incubating temperature of the TEI-TES and CEI was raised to 35.7°C and 35.6°C respectively. The temperature inside the TES unit sharply increased and reached a maximum temperature of 193°C at 2 p.m. The high temperature inside the TES unit changed the PCM phase from solid state to liquid state.

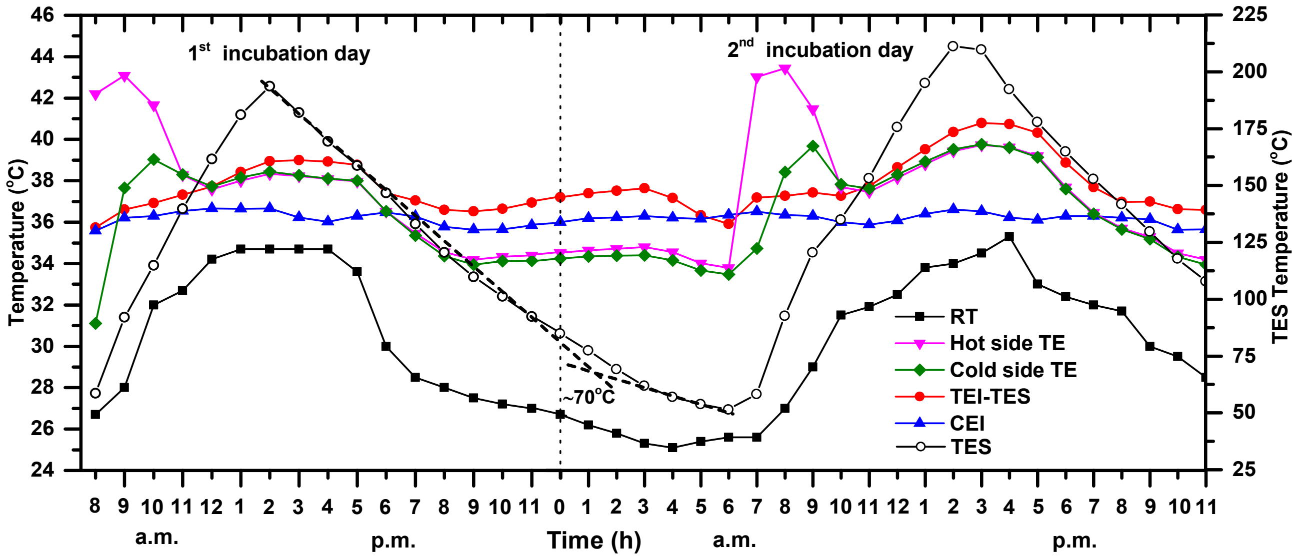

Figure 4. Temperature profiles over the 1st and 2nd days of incubation period of the following: TEI-TES, CEI, RT, hot and cold sides of TE module, and TES

There was a difference in temperature between the hot and cold sides of the TE module during 8 a.m. and 12 noon each day, indicating that the TE module transferred heat from the cold side to the hot side through the TE material (heat pump mode), thereby keeping the TEI-TES temperature within the required incubating temperature of 35.7-37.7°C. The operation of the TE module was stopped when the temperature was the same on each side; however, the TEI-TES continued to maintain the temperature within the incubating range even when the air-flow fans were turned off between 12 noon and 6 p.m. This resulted in sufficient heat being transferred from the TES unit to the TEI chamber through the stainless steel pipes by conductive heat transfer. The temperature inside the TEI-TES, which was switched on at 6 p.m., could be controlled within the optimum incubating range after 6 p.m., which indicates that the TES has enough thermal energy capacity to maintain the incubating temperature inside the TEI-TES until 6 a.m. the next day. On the 2nd day of incubation, the TE module provided heat for the 4 hours between 6–10 a.m. by deriving heat from the surroundings to the TEI chamber.

The TEI-TES reached a critical temperature of about 40°C, a slightly higher temperature than the optimum incubating temperature between 4–5 p.m. When the temperature reached this level, the temperature inside the TES increased up to 220°C, resulting in a continuous excess heat transfer from the TES unit to the TEI chamber (heat loss) through the two stainless pipes. Heat loss, especially in the afternoon, needed to be reduced in order to maintain a correct heat flow from the

TES to the TEI at a correct temperature. This was achieved by having a thick layer of rockwool insulation in the space between the TES and TEI units.

Over the 2-day period, the TE module worked for about 4 hours and then stopped when the inside temperature of the TES reached 150°C. This means that the temperature of the TEI-TES varies within the range of the optimum incubating temperature during daytime operation by having sufficient heat transferred from the TES unit to the TEI chamber through the two stainless steel pipes. The temperature inside the TEI-TES thus is maintained in the desirable incubating temperature range. Compared with the CEI, the temperature of the TEI-TES fluctuates a little more than that of the CEI, and is slightly higher than the temperature maintained in the CEI (36-37°C). This is due to the heat transfer from the TES unit. An outcome of this is that the metabolic process of the chick embryos in the TEI-TES is higher than that inside the CEI [1].

As can be seen in the temperature profile of the TES during the discharge process between 3 –10 p.m. (Figure 4), the temperature sharply decreases, followed by a moderate decrease till 3 a.m. and a further slowing of the rate of decrease until 8 a.m., at which time the TE module starts to generate heat, powered by the PV panels. During 3 p.m .– 8 a.m., which is the period of heat discharge, the TES discharges thermal energy via two mechanisms: sensible heat discharge (a larger drop in thermal energy) and latent heat discharge (a smaller drop in thermal energy). These thermal energy-releasing processes correspond to the fundamentals of latent heat storage materials, which work in a nearly isothermal way based on the phase change mechanism. The intersection of both mechanisms occurs at about 70°C, which is congruent with the melting point of paraffin wax (PCM).

Fundamentally, the power generated by PV panels is proportional to the intensity of the solar irradiance. In Thailand, as anywhere, the weather varies from day to day — sometimes overcast and raining, sometimes clear skies and warm or hot. These variable conditions obviously impact on the workings of any solar-powered device. Figure 5 presents the temperature profile of the TEI-TES on the 18th and 19th days of the incubation period, compared with that of the CEI. On these two days the weather was heavily overcast. The temperature inside the TES increased sharply and steadily over the period from 9 a.m. to 2 p.m., reaching the highest temperatures of 162.2°C on the 18th day and 176.9°C on the 19th day. However, these temperatures were lower than the 210-215°C level reached on other cloudless days, thereby reducing the electrical power supplied by the PV panels to the heating element circuit of the TES unit. The RT was relatively lower (26-27°C) between 9 p.m. and 6 a.m. the following morning, causing a larger temperature difference between the TEI-TES and RT, which was the effect of the overcast weather. Thus, the thermal energy capacity inside the TES was reduced, causing a drop in the temperature inside the TEI-TES to less than 36°C between 3–7 a.m. on both days. The temperature inside the TEI-TES was achieved and maintained within the range of optimum incubating temperature from 8 a.m. to 3 a.m. of the next day. The TE module also worked for about 4 hours per day, transferring heat from the surrounding air into the TEI chamber. This transfer of heat stopped when the temperature inside the TES exceeded 150°C. In this situation the CEI maintained the incubating temperature better than the TEI. The TEI-TES thus seems to be able to work under cloudy conditions without electricity from the national grid, even with a full energy load for incubating chicken eggs.

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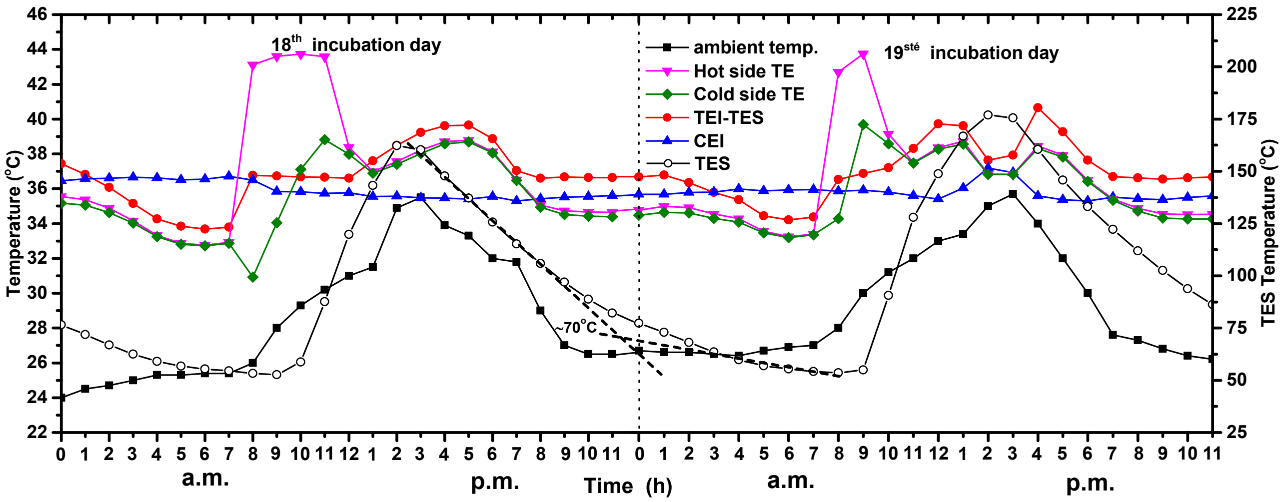

Figure 5. Time dependence of the temperature profiles (for TEI-TES, CEI, RT, hot and cold sides of TE module and TES) over the 18th and19th days of incubation period

To discuss the performance of temperature control in more detail, the average daily temperatures of the TEI-TES and CEI during the incubation period are presented in Figure 6. It was observed that the incubating temperatures of the TEI-TES and CEI were mostly maintained within the optimum incubation temperature range for chicken egg hatching (36-39°C) [1-3]. On the 18th-19th days of incubation the incubating temperatures of both incubators were gradually lowered due to the effect of cloudy days on the performance of the PV panels (Figure 5). The daily average incubating temperatures of the TEI-TES at 36.7-38.8°C were achieved and maintained over the incubation period, which is comparable to those of the CEI (35.8-37.4°C). Thus, the PV-powered TEI-TES seems to be able to maintain the appropriate incubation temperature necessary for chicken eggs to hatch.

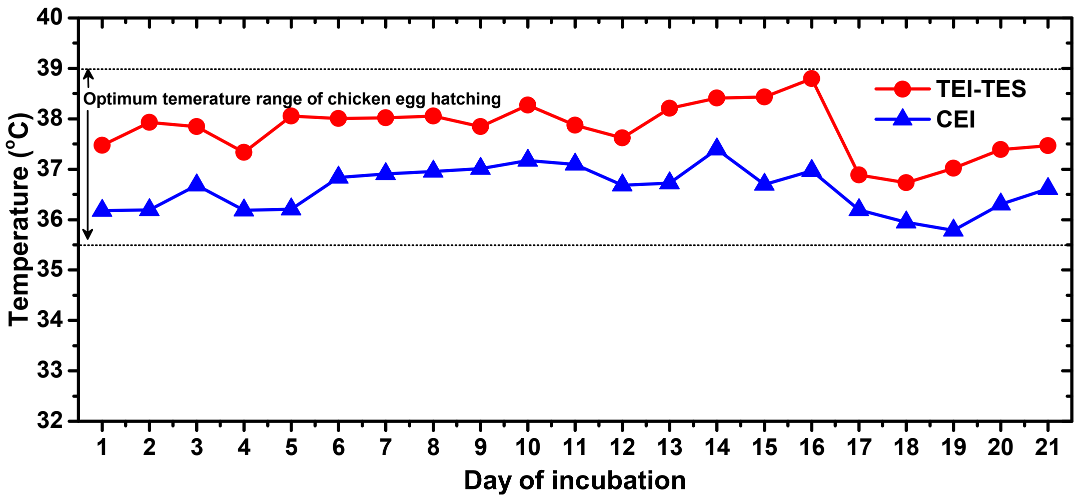

Figure 6. Average incubating temperatures of TEI-TES, compared with CEI, during the incubation period

Another important factor necessary for enabling fertile chicken eggs to stimulate the embryonic development until hatching is the moisture level, which must be controlled and maintained between 60-80% RH [1, 2]. Humidity is a crucial factor in preventing excess moisture loss from chicken eggs through the pores of the eggshell and membranes. It is well known that the

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moisture content in the air is also dependent on the ambient temperature. Generally, the RH decreases with increasing room temperature during the heating process. Therefore, a water pan is placed inside the incubator in order to prevent a low RH resulting from the heating process (Figure 3). Figure 7a shows % RH of the TEI-TES, compared with the CEI, over 24 hours on the 1st incubation day. At the beginning, the % RH of both incubators were the same. The RH of the CEI gradually increased and then became constant at about 72±1.5% throughout the day. In the case of TEI-TES, the RH was kept constant at about 66±0.9%, also the correct humidity level for chicken egg hatching over the incubation period. However, the RH of the TEI-TES was lower than that of the CEI because the incubating temperature of the TEI-TES was higher than that of the CEI. Figure 7b shows the average daily % RH of the TEI-TES, together with that of the CEI, over the incubation period. The average daily RH of the TEI-TES during the incubation period was 66±0.2%, while that of the CEI was 72±0.1%. The % RH of the TEI-TES is in agreement with values from previous studies and developments of chicken egg incubators, e.g. solar-powered chicken egg incubators [7], the conveyor egg-hatching rotation system [6] and TEI [11].

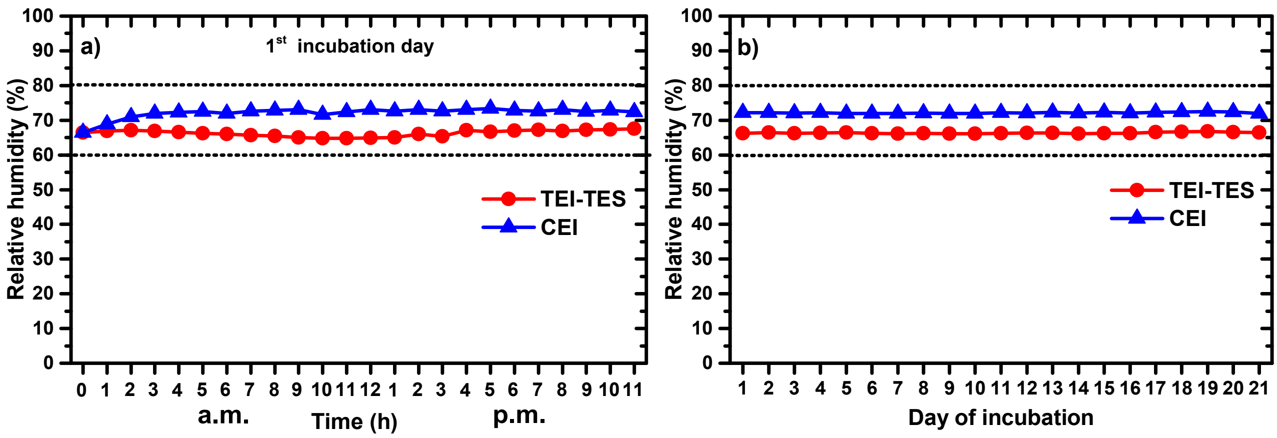

Figure 7. (a) % RH on 1st incubation day; (b) average % RH over an incubation period

CONCLUSIONS

The TEI-TES can achieve and maintain an optimum incubating temperature range of 36.7-38.8°C and a correct RH of 66±0.2% under the climatic conditions of Thailand throughout the whole chicken-egg hatching period of 21 days. Therefore, the PV-powered TEI-TES has the potential for chicken hatching in remote areas without available electricity infrastructure.

ACKNOWLEDGEMENTS

We are grateful to the National Research Council of Thailand (NRCT), through Naresuan University, for providing financial support (Grant no. R2559B116). The School of Renewable Energy Technology and the Research Centre for Academic Excellence in Applied Physics, Naresuan University are also thanked for their general support.

REFERENCES

1. A. M. Kingori, "Review of the factors that influence egg fertility and hatchabilty in poultry", *Int. J. Poult. Sci.*, **2011**, *10*, 483-492.

Maejo Int. J. Sci. Technol. **2017**, *11*(02), 148-157

2. E. S. Nakage, J. P. Cardozo, G. T. Pereira, S. A. Queiroz and I. C. Boleli, "Effect of temperature on incubation period, embryonic mortality, hatch rate, egg water loss and partridge chick weight (*Rhynchotus rufescens*)", *Rev. Bras. Cienc. Avic.*, **2003**, *5*, 131-135.
3. Hubbard Co., "Incubation guide", **2011**, www.hubbardbreeders.com (Accessed: July 2016).
4. A. Lourens, H. van den Brand, R. Meijerhof and B. Kemp, "Effect of eggshell temperature during incubation on embryo development, hatchability, and posthatch development", *Poult. Sci.*, **2005**, *84*, 914-920.
5. A. Lourens, H. van den Brand, M. J. W. Heetkamp, R. Meijerhof and B. Kemp, "Effects of eggshell temperature and oxygen concentration on embryo growth and metabolism during incubation", *Poult. Sci.*, **2007**, *86*, 2194-2199.
6. M. B. Ramli, H. P. Lim, M. S. Wahab and M. F. M. Zin, "Egg hatching incubator using conveyor rotation system", *Procedia Manufact.*, **2015**, *2*, 527-531.
7. K. G. Mansaray and O. Yansaneh, "Fabrication and performance evaluation of a solar powered chicken egg incubator", *Int. J. Emerg. Technol. Adv. Eng.*, **2015**, *5*, 31-36.
8. H. Alam and S. Ramakrishna, "A review on the enhancement of figure of merit from bulk to nano-thermoelectric materials", *Nano Energy*, **2013**, *2*, 190-212.
9. A. J. Minnich, M. S. Dresselhaus, Z. F. Ren and G. Chen, "Bulk nanostructured thermoelectric materials: Current research and future prospects", *Energy Environ. Sci.*, **2009**, *2*, 466-479.
10. X. Zhang and L.-D. Zhao, "Thermoelectric materials: Energy conversion between heat and electricity", *J. Materiomics*, **2015**, *1*, 92-105.
11. E. Singhadet, T. Suriwong, S. Jiajitsawat and P. Tanarak, "Performance comparison of heating coil and thermoelectric egg incubators", *Burapha Sci. J.*, **2014**, *Special Vol.2014*, 271-276 (in Thai).
12. P. Savatdipap, "Development of a thermoelectric egg incubator," *Master Thesis,* **2003**, King Mongkut's University of Technology Thonburi, Thailand.
13. A. Sharma, C. R. Chen, V. V. S. Murty and A. Shukla, "Solar cooker with latent heat storage systems: A review", *Renew. Sust. Energy Rev.*, **2009**, *13*, 1599-1605.
14. S. M. Hasnain, "Review on sustainable thermal energy storage technologies, Part I: Heat storage materials and techniques", *Energy Convers. Manage.*, **1998**, *39*, 1127-1138.
15. Y. Tian and C. Y. Zhao, "A review of solar collectors and thermal energy storage in solar thermal applications", *Appl. Energy*, **2013**, *104*, 538-553.
16. A. Sharma, V. V. Tyagi, C. R. Chen and D. Buddhi, "Review on thermal energy storage with phase change materials and applications", *Renew. Sust. Energy Rev.*, **2009**, *13*, 318-345.

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