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Comparative Temperature Distribution Characteristics and Thermal Efficiency of a Conventional Rice Cooker (CRC) and a Vapor Chamber Rice Cooker (VRC)

Viroj LIMKAISANG[1,*] and Wasan SRIMUANG[2]

[1] *Department of Applied Physics, Faculty of Sciences and Liberal Arts, Rajamangala University of Technology Isan, Nakhon Ratchasima 30000, Thailand*
[2] *Heat Pipe Heat Exchanger Research Laboratory, Department of Mechanical Engineering, Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, Nakhon Ratchasima 30000, Thailand*

([*]Corresponding author's e-mail: viloj.limkaisang@gmail.com)

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Abstract

A conventional rice cooker (CRC) and a vapor chamber rice cooker (VRC) were designed and constructed in equal mass, capacity, material, depth and inside diameter. The temperature distribution characteristics and thermal efficiency of both CRC and VRC were compared. The water boiling test was conducted to calculate the thermal efficiency of both rice cookers. The results indicate that the temperature distributions of water in the rice cookers show clearly different characteristics. The VRC had a higher thermal efficiency than the CRC by around 5.57 %. Copper nanoparticles mixed in the liquid water and used as a working fluid in the VRC enhanced the thermal efficiency by around 2.02 %.

Keywords: Rice cooker, vapor chamber, heat pipe, energy, efficiency

Introduction

Electrical rice cookers or conventional rice cookers (CRC) are necessary devices in the kitchen for cooking rice. They have many advantages being cheap, easy to use, and require less time for cooking. The basic principle of the CRC is to convert electrical energy into heat energy using a heater. The heat from the heater attached to the external wall of the bottom vessel transfers heat to the rice and water by heat conduction only. Low energy consumption of electrical rice cookers is desired to save energy but reports about improving their efficiency are still lacking. A strong point in current research is improved heat transfer by combined heat convection.

However, there are patents that relate to the improvement of thermal efficiency of rice cookers. Schultz *et al*. [1] designed a double walled cooking pot which has a bottom wall made of conductive material. Sa *et al*. [2] have claimed improvement by adiabatic vacuumed insulation around the rice cooker vessel. The heater in the rice cooker of [2] has a large surface area, and it was overlaid on the bottom of the vessel cooker. Wang *et al*. [3] designed a heater with the coils wrapped around the bottom and walls of the cooker. The rice cooker of Oota *et al*. [4] saves energy by controlling the electric current that is supplied to the heater. Aoshima *et al*. [5] designed a rice cooker with 2 separate heaters. One heater was attached to the bottom and middle wall for the rice and water zone, while another one was attached to upper wall in the water only zone. In a similar patent, the rice cooker of Kwon *et al*. [6] has 2 heaters, and a steam exhaust system for the rice cooker, which can control the pressure during cooking. From the patents of [2-6] the position of the heater significantly affects the performance of rice cookers. Especially, the heat can be transferred by heat-conduction only via the solid vessel wall of the rice cookers. There is only one patent application for a heat pipe cooker by Chung *et al*. [7]. But there is no clear information on the thermal efficiency. The highlight of the current study is to improve the mechanism in heat transfer in a vessel rice cooker by combined convection and conduction heat transfers. A conventional vapor chamber was modified a vessel rice cooker.

The vapor chamber is a type of heat pipe. It is a vacuum container with or without a wick structure lining the inside walls. It can transfer heat via the movement of the working fluid, which fills the internal volume. Without the wick structure, the evaporator section of the vapor chamber is at the bottom of the container because the condensate that returns to this section is assisted by gravity. The operating process begins when the evaporator section of the vapor chamber is heated by a heat source such as a heater. Then, the saturated liquid vaporizes and moves up to the condenser section. After that, some vapor in the condenser section transfers the heat to a heat sink such as the surrounding air. As a result, the vapors condense to a liquid and flow down to the evaporator section.

Many research papers such as Hsieh *et al*. [8], Wong *et al*. [9,10], Lips *et al.* [11] and Tsai *et al.* [12] showed several applications of a vapor chamber and it is widely accepted that it transfers heat with very high efficiency. We used a vapor chamber as a heat transfer device between the heater and the food in the rice cooker. The vapor chamber with similar in research of Tsai *et al.* [12] was developed and a modified rice cooker. The vapor chamber with a 2-phase closed thermosyphon was designed to give a double wall rice cooker, which we term the “vapor chamber rice cooker (VRC)”. Previous research work has reported the application of nanoparticles as a working fluid in vapor chambers [13,14]. The advantages of a nanofluid are enhanced conductivity and boiling heat transfer coefficient inside the vapor chamber.

To the best of authors’ knowledge, research concerning the thermal efficiency of electrical rice cooker has never been reported. The objective of this paper is to investigate the temperature distribution characteristics and thermal efficiency of CRC and VRC. Improving the thermal efficiency of VRC by mixed copper nanoparticles in liquid water was considered.

Materials and methods

Theoretical consideration

The water boiling test [15] was conducted to calculate the thermal efficiency of both rice cookers. The thermal efficiency can be evaluated from;

$$\eta = \left[\frac{m_w \times C_{p,w} \times (T_f - T_i) + (m_v \times C_{p,v} \times (T_f - T_i))}{3600 \times E} \right] \times 100. \qquad (1)$$

where η is the thermal efficiency, m_w is the mass of water in the cooker (kg), $C_{p,w}$ is the specific heat capacity of water (kJ/kg°C), T_f is the final temperature of water (°C), T_i is the initial temperature of water (°C), m_v is the mass of the vessel cooker (kg), $C_{p,v}$ is the specific heat capacity of material used to make the vessel cooker (kJ/kg°C) and E is the energy consumption (kWh). However, we assumed that the effect of latent heat of the working fluid inside the vapor chamber of VRC is negligible.

Prototypes of rice cookers

The prototype of CRC and VRC were designed with the same dimensions, capacity and weight as illustrated in **Figure 1**. The CRC was constructed with a stainless sheet 4 mm thick which was bent into a cylindrical shape. The inside diameter was 186 mm and the depth 91 mm. One side was closed with a stainless disc with the same thickness and outside diameter, and welded together with the cylinder. The VRC was constructed with a stainless sheet 2 mm thick which was bent into 2 cylindrical shapes slightly different in diameter. The inside diameter was 186 mm with a depth of 87 mm. The larger cylinder had an inside diameter of 196 mm and a depth of 98 mm. Each cylinder was closed and welded with a stainless disc which forms the bottom part of the vessel. The small vessel was placed in the big vessel with concentric cylinder, and both vessels were connected at the top ends by a ring disc. The closed space between both vessels is called a vapor chamber. Both CRC and VRC have equal mass (3,700 g), material, capacity, depth and inside diameter. A cover was made of stainless steel, 190 mm in diameter, and used to close the CRC or VRC. **Figure 2(a)** shows a photo of the rice cooker with thermocouples. Water was to the rice cooker for WBT with 80 % of internal volume. A wood net was made with 27 thermocouples and placed in the water in the cooker. **Figure 2(b)** shows a schematic of the locations of the thermocouples in the cooker.

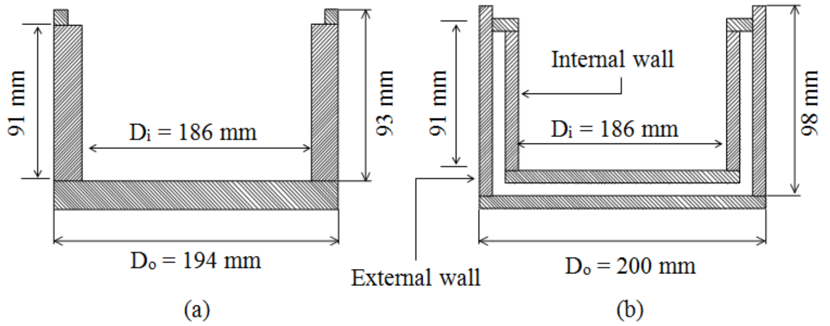


Figure 1 Rice cookers (a) CRC (b) VRC.

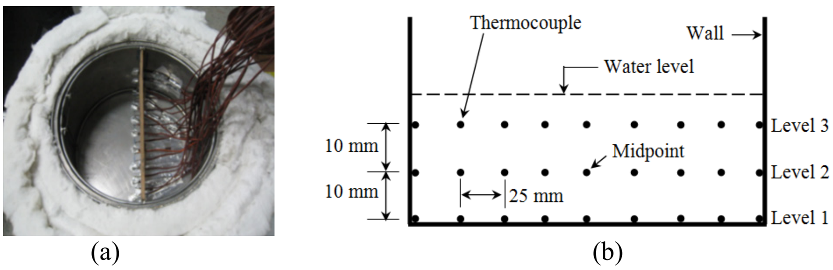


Figure 2 Rice cooker with thermocouples (a) photo of the rice cooker with thermocouples and insulator (b) locations of the thermocouples.

Experimental set-up and procedure

The experimental set-up to investigate the temperature distribution and thermal efficiency of the rice cookers is illustrated in **Figure 3**. The experimental procedure began by turning on the heater and simultaneously recording the temperature. Time was allowed until the water temperature in the cooker at midpoint reached 95.5 °C, the test was stopped and the total time recorded.

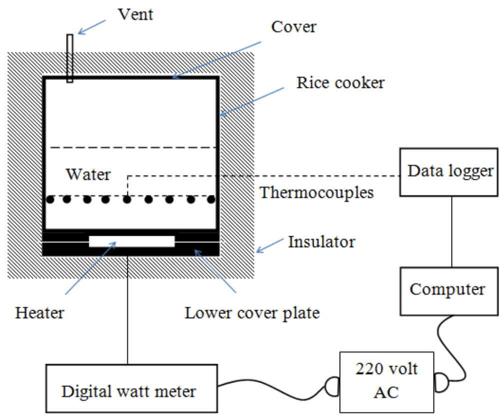


Figure 3 Schematic diagram of test rig.

Results and discussion

Temperatures distribution characteristics in internal volume

When the electrical power was supplied to the heater, the heat from a heater was transfer through the bottom wall to the water in the CRC cooker. But in case of VRC, the heat from the heater was first transferred through the external wall to the working fluid in the vapor chamber, and the heat in the working fluid was then transferred through the internal wall to the water in the cooker. The temperature distribution with time and at 3 levels is shown in **Figure 4**.

The results indicate that the temperature of each level increased differently with time. It was observed that the increasing temperature of level 1 is larger than level 2 and 3 at the same time for both rice cookers. This may be caused by closer proximately of the heater to level 1. For level 1 at 5 min both rice cookers showed that the maximum temperature of CRC increased from 25 °C to 30 °C, but the maximum temperature of the VRC increased from 30 °C to 50 °C, as illustrated in **Figures 4(a)** and **4(b)**, respectively. This is caused the higher temperature in the VRC due to the convection heat transfer of the working fluid in the vapor chamber. At level 2, the temperature distribution of the CRC is rather stable. At this level after 5 min, the temperature of the CRC is same (25 °C), and then at 10 min, the temperature of point 2 increases to a maximum value at point 5 of 30 °C. But at this level after 5 min for the VRC, the temperature increased to 30 °C, see **Figures 4(c)** and **4(d)**. **Figures 4(e)** and **4(f)** show the temperature distribution at level 3 of the CRC and VRC, respectively. It is a similar trend as that of level 2. For the VRC, it was observed that for points 1 and 9 the same value is found for 10 to 45 min. At level 3 after 15 min, the temperature of the CRC increases from 25 °C to reach 35 °C, but the temperature of VRC increases from 25 °C to reach 45 °C, as illustrated in **Figures 4(e)** and **4(f)**, respectively.

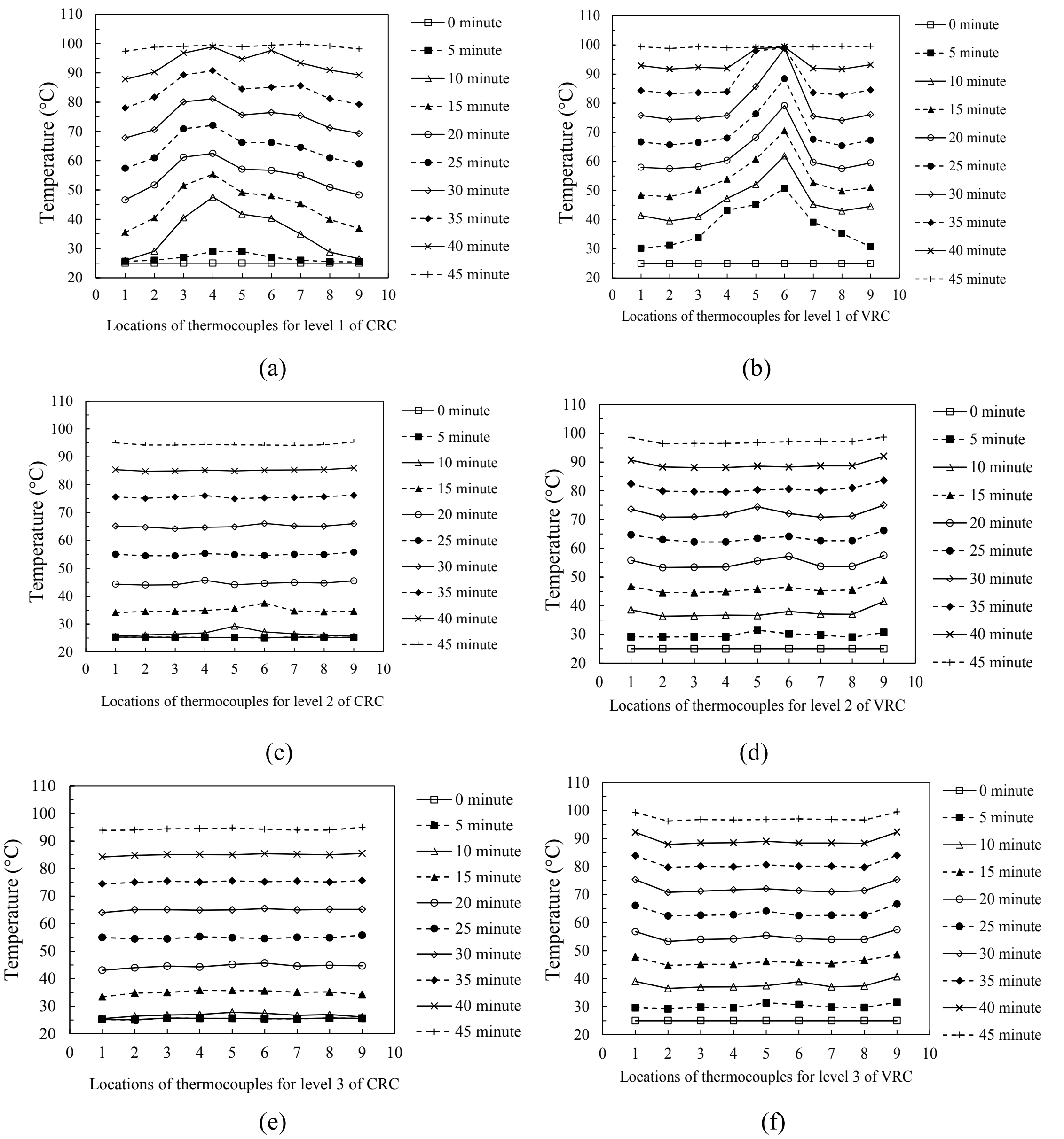


Figure 4 Temperatures distribution of each level with time.

Comparative temperature distribution of each level

The temperature distributions at the same time for the CRC and VRC with different working fluids were plotted for each level. **Figure 5** shows the temperature distribution at level 1 of the CRC and VRC with an increasing time in the range of 10 to 40 min.

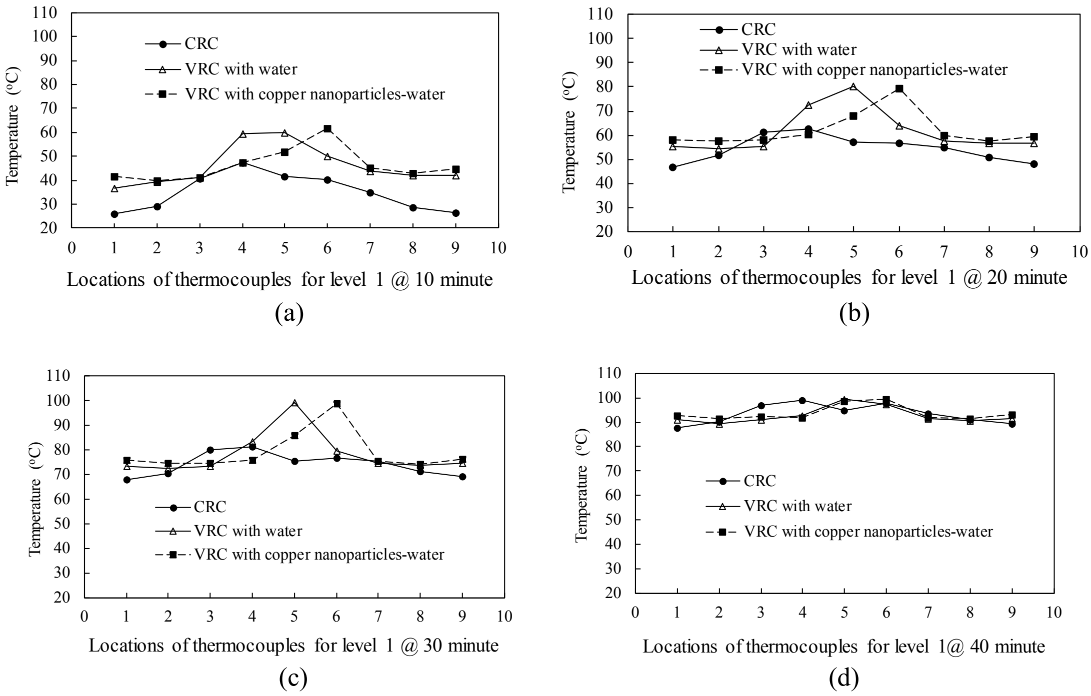


Figure 5 Temperatures distributions of level 1 at different times.

The experimental results indicate that the temperature distributions of both rice cookers increased with time. The temperature near the wall (point 1 or 9) is lowest for CRC, and the VRC with copper nanoparticles-water shows slightly higher temperatures than the VRC with water. The temperature of the CRC is rather stable compared with VRC over all times recorded. The temperature of the VRC is rather stable in the range of point 1 to 3, and then increases to a maximum value at center zone (point 4 or 5 or 6), and its temperature decreases to point 7, and after this point it is rather stable again. At 40 min, the temperature distribution of the CRC and VRC were similar. **Figure 6** shows the temperature distribution at level 2 at different times. It was observed that the temperature increased with time in all cases.

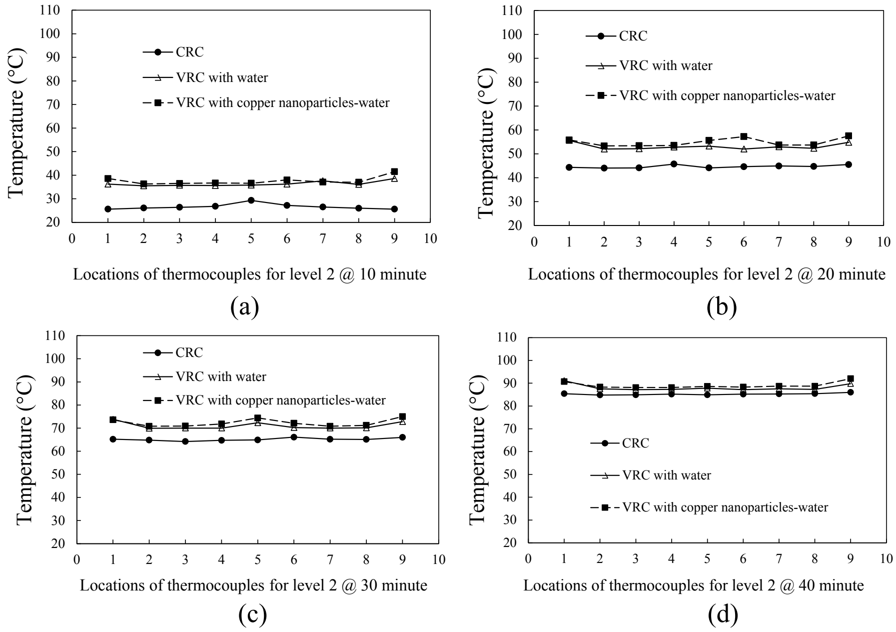


Figure 6 Temperatures distributions of level 2 at different times.

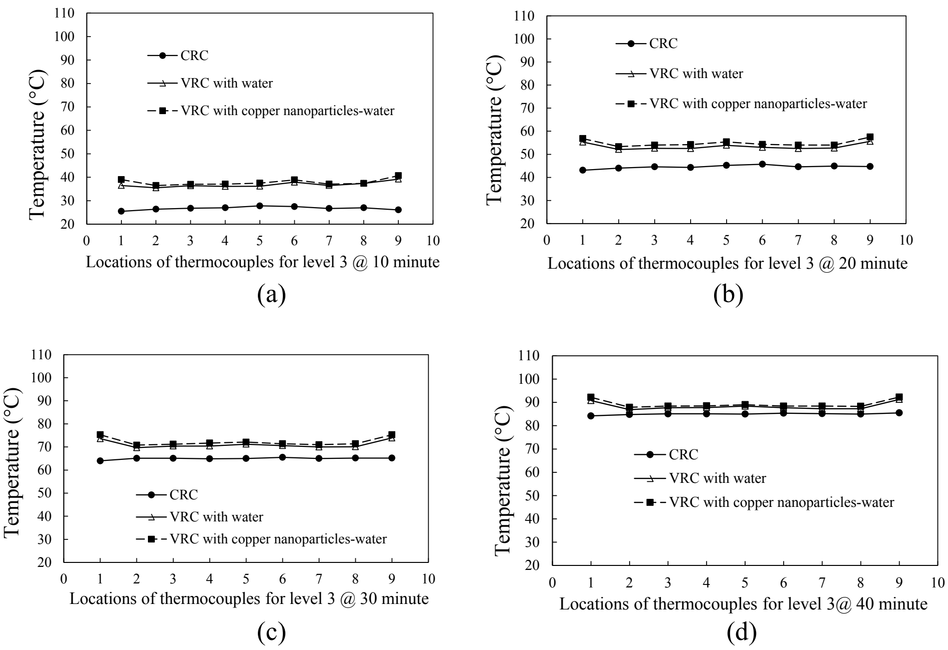
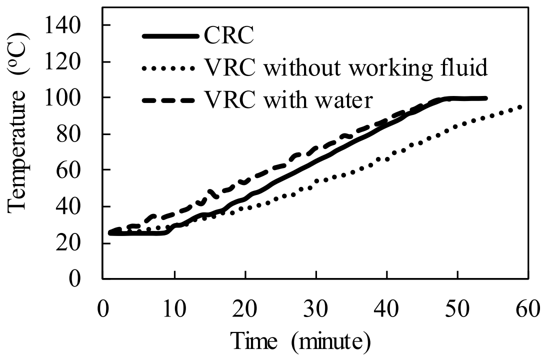


Figure 7 Temperatures distributions of level 3 at different times.

The temperature distribution of CRC and VRC are rather stable. The temperature value of the CRC is the lowest of the cookers tested. The VRC with copper nanoparticles-water has slightly higher temperatures than the VRC with water over all times. With increasing time, the temperature of the CRC moves up to reach the VRC. The temperature at the wall (point 1 or 9) is highest for the VRC. **Figure 7** shows the temperature distribution at level 3 with different time. The results are a similar to level 2 in their distribution characteristics and the temperature. It can be concluded that the working fluid in the VRC clearly affects heat transfer in the rice cooker.

Increasing temperature with operating time of rice cookers

The increasing temperatures of the water at the midpoint (point 5 of level 2) of the CRC, VRC with water and the VRC without working fluid are compared in **Figure 8(a)**. It was observed that the first 10 min after suppling electrical power to the heater, the temperature of the CRC is rather stable. After this point, the temperature linearly increases. The increasing temperature of VRC is linearly increases from the start of the test. However, the increasing temperature of both CRC and VRC shows a difference in slope. The VRC with working fluid takes less time than CRC to approach the maximum temperature.



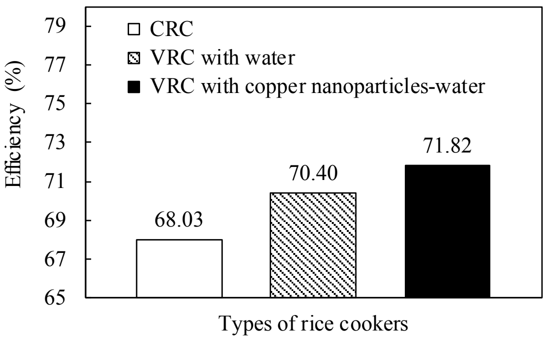


Figure 8 Comparison between CRC and VRC (a) increasing temperatures and (b) thermal efficiency.

Thermal efficiency of rice cookers

The initial and final temperatures of water on boiling test and results of energy consumption were used in a calculation of the thermal efficiency of the CRC and VRC by using Eq. (1). The comparison of the thermal efficiency of the rice cookers is shown in **Figure 8(b)**. The results indicate that the VRC has higher thermal efficiency than the CRC. The thermal efficiency for the CRC, VRC with water and VRC with copper nanoparticles-water are 68.03, 70.40 and 71.82 %, respectively.

Conclusions

From this study it can be concluded that the temperature distribution characters of CRC is clearly different from the VRC. The increasing temperature at startup of the CRC and VRC is very different in the first 10 min. The VRC with water has higher thermal efficiency than the CRC by around 3.48 %. The use of copper nanoparticles in water as working fluid in the VRC can enhance its thermal efficiency by around 2.02 %. Therefore, the VRC is appropriate for cooking and can save energy.

Acknowledgements

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