ORIGINAL ARTICLES

The Study of A Cashew Nut oven using A Thermosyphon Heat Exchanger using Nut Shell as Fuel

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ABSTRACT

The aim of this study was to design a cashew nut oven using a thermosyphon heat exchanger to exchange heat from the nut shell combustion chamber and take it to the oven. Thirty stainless steel thermosyphons with an outside diameter of 37.5 and 1.5 mm. wall thicknesses were used. The condenser and evaporator were equal in length at 300 mm. and R134a was used as working fluid. The air velocities were 0.5, 1 and 1.5 m/s. The results shown that the thermosyphon heat exchanger can be transferred heat from the nut shell chamber to the oven of 64.96 kW/m² and the air velocity was 1.5 m/s. Temperature distributions in the oven showed a high temperature in the oven of 62°C with air velocity was 0.5 m/s. From this study it was discovered that TPHE can be used to exchange heat from the combustion chamber directly and temperature from this study were in the range that could be used in any drying process.

Key words: Cashew nut, Nut shell, Thermosyphon, Heat exchanger.

Introduction

Development in agriculture is a continuous process. It is necessary to develop existing technology to suit the user. The aim is to increase productivity and add value to products. Cashews grown in Thailand are primarily for processing and exportation. This study was designed to develop a new approach and focuses on the study of burning the cashew nut shells for use as the heat source then using a TPHE heat exchanger. Heat is used in drying the cashew nuts. The technology is simple but sophisticated technology. These results may be contributed to production costs decreased. TPHE was designed to reduce the consumption of primary energy. The thermosyphon has been proved as a promising heat transfer device with very high thermal conductance. It was found that the effective thermal conductivity of the thermosyphon exceeds that of copper by 200-500 times, Dunn and Reay (1994). Previous work has been conducted on the thermal performance of TPHE, such as the design, construction and testing of a heat pipe heat exchanger with a heat exchange potential of 800W for heat recovery from an operating theatre in a hospital. During those tests, the rate of heat input to the evaporator section was maintained within 20W–400W. The thermal performance of TPHE was at low temperature (15°C–55°C) operating conditions and used methanol as the working fluid. Noieibangban and Majideian (2000). Other work includes the design and testing of a waste heat recovery system using a heat pipe heat exchanger for heating an automobile using its exhaust gas, which indicates the benefit of exhaust gas heating, Yang et al. (2003). Experimental work on investigation of a thermosyphon solar water heater system fitted with helical twisted tape of various twist ratios were compared with a plain tube collector. The results show that heat transfer enhancement in a twisted tape collector is higher than the plain tube collector with minimum twist ratio and gradually decreases with increase in twist ratio, Jaisankar et al. (2009). Similar work investigated a heating enclosure compared with a conventional enclosure and a thermosyphon-assisted enclosure these experiments showed that the thermosyphon-assisted enclosure presented a very uniform temperature distribution, Fernando and Mantenli (2006). Investigation of a heating enclosure compared with a conventional enclosure and thermosyphon-assisted enclosure showed that the thermosyphon-assisted enclosure presented a very uniform temperature distribution, Fernando and Mantenli (2006), Mantelli et al. (2003). However, generally heat exchangers can be separated into four types consisting of tubular heat exchangers (double pipe, shell and tube, coil tube) plate heat exchangers (gasketed, spiral, plate coil, lamella) extended surface heat exchangers (tube-fin, plate-fin) regenerators (fixed matrix, rotary); all types are used in general industry (Liu, 1992; Mantelli,

2. TPHE design:

The TPHE prototype has been designed based on Data item No. 80013, Engineering Sciences Data Unit, Anon (1980). The conventional thermosyphon shown in Figure 1 consists of a container and an amount of working fluid. It can be separated into 3 sections: evaporator, adiabatic and condenser sections. When the evaporator section receives heat, the working fluid vaporizes and flows to the condenser section. At the condenser section, the vapor was condensate returns to the evaporator section by gravitational force. The conventional thermosyphon must operate only in a vertical position because it employs gravitational force to return the condensate to the evaporator section. In this study, the heat exchangers used was a thermosyphon.

The design conditions for the cashew nut oven were to reduce the humidity of the cashew nuts. The scope design parameters were:
- Heat source was the cashew nut shell burning
- 30 thermosyphon made from Stainless 304
- Temperature of Air inlet of 28 °C
- Inner oven temperature requirement of 60 °C
- The working fluid of R134a
- Air velocities were 0.5, 1 and 1.5 m/s

![Fig. 1: Schematic of the thermosyphon and thermal resistance network.](image)

3. Experimental Set-up:

Figure 2 shows the components of the cashew nut, the nut shell combustion chamber and experimental set-up; Figures 3 and 4 shows a schematic diagram of the experimental apparatus that consists of two main sections. The first section was TPHE and the combustions chamber, the second was the oven chamber. The geometry of
TPHE and combustion chamber was 0.9 x 0.9 x 0.9 m. The combustion chamber had 30 tubes of stainless thermosyphon installed within it. The evaporator section was 300 mm; the condenser section was 300 mm and without an adiabatic section. The heat source comes from four cashew nut shell burners. Sixteen thermocouples were installed to collect data (Yokogawa DX200 with ±0.1°C accuracy, 20 channel input and -200°C to 1100°C measurement temperature range) (Stephanie Bell, 2001) as well as type K thermocouples (OMEGA with ±0.1°C accuracy). An air flow meter used with pitot tube probes (Testo 445 ± 0.2%) for checking air flow in the system. The frequency inverter used in this work was an IGBT vector inverter model 600 which was operated manually, Inverter operation manual (1998), with the range of frequency control 0.5 - 240 Hz with ± 0.1% accuracy and it was used to control fan speed in order to control the mass flow rates of air. The dimensions of the oven were 1.8 x 1.8 x 2 m. The combustion chamber and the oven are made from 2 steel sheets with a sheet thickness of 1.5 mm. Central blocks with glass fiber insulation thickness of 35 mm, designed to take hot air into the bottom oven and flow upward as shown in Figures 3 and 4.

Fig. 2: (a) Component of cashew nut (b) Cashew nut shell burning and combustions chamber (c) Experimental set up.

4. Procedure:

4.1 Heat transfer rate of TPHE Analysis:

The following equations were used to calculate the heat transfer and checked error analysis:

\[
Q = \dot{m} c_p (T_{out} - T_{in})
\]

Thus:

\[
Q = f(\dot{m}, T_{out}, T_{in})
\]

and error analysis of heat transfer to obtain:
In this experiment the heat transfer rate can be calculated by the following equation \( (3) \).

\[
W_Q = \left[ \left( \frac{\partial Q}{\partial m} \times W_m \right)^2 + \left( \frac{\partial Q}{\partial T_{out}} \times W_{T_{out}} \right)^2 + \left( \frac{\partial Q}{\partial T_{in}} \times W_{T_{in}} \right)^2 \right]^{0.5}
\]

when \( Q = \dot{m} C_p (T_{out} - T_{in}) \), \( A_c \) is the entire outer surface area of tube in the condenser, section, \( q \) is the heat flux, \( Q \) is the heat transfer rate, \( \dot{m} \) is the mass flow rate, \( C_p \) is the specific heat capacity at constant pressure, \( T_{out} \) is the outlet temperature at condenser section and \( T_{in} \) is the inlet temperature at condenser section.

**Fig. 3:** Diagram of the experimental set-up.

**Fig. 4:** Design of experimental set-up.
4.2 Uncertainty Analysis:

Calculating standard uncertainty for a type A evaluation. When a set of several repeated readings were taken (for a Type A estimate of uncertainty), \( \bar{x} \) (Arithmetic mean), SD (Standard deviation), can be calculated using the following equation.

\[
\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{n}
\]

(5)

\[
SD = \sqrt{\left(\frac{x_1 - \bar{x}}{n} + \frac{x_2 - \bar{x}}{n} + \ldots + \frac{x_n - \bar{x}}{n}\right)^2}
\]

(6)

\[
u_{i,\text{typeA}} = \frac{SD}{\sqrt{n}},
\]

(7)

where \( n \) was the number of measurements in the set.

Calculating standard uncertainty for a type B evaluation. Using the following Eq. (8)

\[
u_{i,\text{typeB}} = \frac{a}{\sqrt{3}}
\]

(8)

where \( a \) is the semi-range (or half-width) between the upper and lower limits.

Combined standard uncertainty calculated by Type A and Type B evaluations can be combined, shown by \( u_c \) Eq. (9)

\[
u_c = \sqrt{\left(\nu_{i,\text{typeA}}\right)^2 + \left(\nu_{i,\text{typeB}}\right)^2 + \ldots \text{etc.}}
\]

(9)

Expand uncertainty, shown by the symbol \( U \).

\[
U = ku_c
\]

(10)

<table>
<thead>
<tr>
<th>Table 1: Uncertainty Analysis</th>
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<tr>
<td>Note</td>
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<td>4.</td>
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<td>5.</td>
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</table>

A particular value of coverage factor gives a particular confidence level for the expanded uncertainty. Most commonly overall uncertainty using the coverage factor \( k=2 \), to give a level of confidence of approximately
95%. Stephanie (2001) (k=2 is correct if the combined standard uncertainty is normally distributed). Some other coverage factors (for a normal distribution) are:

- \( k=1 \) for a confidence level of approximately 68%
- \( k=2.5 \) for a confidence level of 99%
- \( k=3 \) for a confidence level of 99.7%

The uncertainty analysis for this study shows in Table 1.

**Result and Discussion**

**5.1 Performance of TPHE:**

Figure 5 shows the performance of TPHE compared with the temperature in the combustion chamber and the surface temperature of the thermosyphon at the condenser. From this figure the performance of the TPHE can be explained. From this insight the thermosyphon can be transfer heat from the evaporator section in the combustion chamber to condenser section as well. The temperature in the combustion chamber is as high temperature of 100°C to 550°C and temperature was undulating and very inconstant. Thereafter the TPHE received heat and transferred the heat to the condenser section. It should be note that the temperature at the condenser surface was constantly distributions under the flames in the combustion chamber. The TPHE can be transfer heat to the condenser surface of the thermosyphon and this was measured as 180 to 300°C depends on the flames in the combustion chamber. The temperature showed the performance of the TPHE for heat exchange and the thermosyphon can accumulate heat from some of the surfaces of the condenser section. Higher temperatures in the combustion chamber can result from the thermosyphon accumulating heat itself.

![Fig. 5: Operations of TPHE.](image)

**5.2 Effect of air velocity on temperature distributions:**

Temperature distributions in the oven mean good air circulation. This can result in drying in the future. This experiment varies the air velocity and 0.5, 1 and 1.5 m/s was used to study the effect of air velocity on temperature distributions in the oven. Figure 6 shows the experimental results at air velocity of 0.5 m/s and from this study the start time of temperature was 0-50 minutes and then the temperature of the oven was highest and constant between 60°C to 70°C which is the optimum temperature for the drying process. After that temperature in the oven was swing base on the frame up of cashew nut in the combustion chamber. From this experiment it was found that the bottom oven temperature was higher than the temperature in the middle and top of the oven because hot air from TPHE inlet from bottom of oven to middle and top as the result temperature at bottom was high. Velocity has little effect on temperature difference. At velocities of 1 and 1.5 m/s temperature distribution was very close because locations in the middle and top of the oven in position flow is laminar flow and as a result both stream air flow and temperature is easy to transfer.
When air velocity increased to 1 m/s the temperature distributions in the oven decreased because high air velocity affected to flow rate as high. If heat is taken out of the oven faster compared with low air velocity then that can bring about very close temperatures in all locations in the oven as shown in; Figure 7. However oven temperatures from this experiment were 50 to 60°C which can also be used in certain types of drying process.

Figure 8. When air velocity was increased to 1.5 m/s the trend of temperature distributions were similar to air velocity of 1 m/s, the only difference was air velocity at 1 m/s was lower as a result of air velocity increase. Air velocity in the oven at high temperatures in all locations was very close but the temperature decreased because air velocity was high and the cumulative heat in the oven decreased compared with air velocity of 0.5 and 1 m/s. Figure 8 shows the range of temperature distributions was 50-58°C.

Figure 9 Illustrates comparisons for each velocity thermocouple attached to the middle of the oven to compare temperatures in the oven when the air velocity changed. This figure shows when air velocity increased, the temperature of the oven decreased directly as a result of velocity. Air velocity increased resulting in convection leaving the oven rapidly and the temperature of the oven decreased when air velocity increased for this experiment with air velocity at 0.5 m/s showing high temperature in the oven at 62°C.
5.3 Effect of air velocity on heat transfer rate:

For the heat transfer rate of TPHE shown in Figure 10, the heat transfer rate was calculated following equations (1) (2) (3) (4) and (5). When considering the heat transfer rate of TPHE air velocity at 1.5 m/s showed high heat transfer rate 64.96 kW/m² in contrast with temperature in Figure 8 because when the air velocity was high it meant m³ or mass of air flow rate was high then it was possible to calculate heat transfer rate height accordingly. When air velocity decreased heat transfer decreased, as shown in Figure 10 as a result of the change in air velocity.
Fig. 10: Heat transfer rate of TPHE.

6. Conclusion:

TPHE in this study can be used to exchange heat from combustion chamber to the oven. Air velocity effects on temperature and heat transfer rates on the other contrary. Heat from TPHE can be using in the drying process. The extremes heat was 62 °C at air velocity 0.5 m/s. The maximum heat transfer rate of 64.96 kW/m² at air velocity of 1.5 m/s. In the further work should be really cashew nuts drying process for study drying conditions optimizations.

Nomenclature:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>A</td>
<td>total heat transfer area (m²)</td>
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<tr>
<td>C</td>
<td>capacity rate (kJ/s°C)</td>
</tr>
<tr>
<td>D</td>
<td>diameter (m)</td>
</tr>
<tr>
<td>Do</td>
<td>outside diameter (m)</td>
</tr>
<tr>
<td>Di</td>
<td>inside diameter (m)</td>
</tr>
<tr>
<td>cp</td>
<td>specific heat of the ambient air (kJ/kg°C)</td>
</tr>
<tr>
<td>ṁ</td>
<td>mass flow rate (kg/s)</td>
</tr>
<tr>
<td>Q</td>
<td>heat transfer (W)</td>
</tr>
<tr>
<td>q</td>
<td>heat transfer rate (kW/m²)</td>
</tr>
<tr>
<td>Z</td>
<td>thermal resistance (°C/W)</td>
</tr>
<tr>
<td>T</td>
<td>temperature (°C)</td>
</tr>
<tr>
<td>ΔT</td>
<td>temperature difference (°C)</td>
</tr>
<tr>
<td>c</td>
<td>condenser</td>
</tr>
<tr>
<td>h</td>
<td>evaporator</td>
</tr>
<tr>
<td>x̄</td>
<td>arithmetic mean</td>
</tr>
<tr>
<td>SD</td>
<td>standard deviation</td>
</tr>
<tr>
<td>ns</td>
<td>number of measurement in the set</td>
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<tr>
<td>ci</td>
<td>sensitivity coefficient</td>
</tr>
<tr>
<td>ui</td>
<td>standard uncertainty</td>
</tr>
<tr>
<td>uc</td>
<td>combine standard uncertainty</td>
</tr>
<tr>
<td>U</td>
<td>expand uncertainty</td>
</tr>
<tr>
<td>k</td>
<td>coverage factor</td>
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Acknowledgement

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