Inlet Water Temperature Reduction in Ice Production Machine

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This research proposes a performance improvement method of a tube ice production machine using the installation of a heat exchanger. At the end of an ice production process, there are cold rejected water from the defrost process. The cold rejected water are stored at the sump below the cooling tower. A prototype heat exchanger is submerged inside the sump. Incoming water for the next cycle was flown through the heat exchanger and are cooled before entering the cooling tower. The results showed that there are reduction in power consumption and the average production time reduced by 7.58 percent. As the system is more efficient, the machine’s production capacity is increased by 6 percent while being able to reach the payback period of the investment in less than five months.

Keywords: Heat Exchanger, Freezing, Ice Production, Waste Recovery, Economical Solutions

Introduction

As ice is one of the largest consumable products in hot climate regions. Ice production facilities relied on a HVAC system. Most ice production facilities suffered from high energy costs as well as insufficient production capacity to serve the demands. In the past, there are attempts toward the improvement of a consumable tube ice production machine. Researchers had investigated the overall solidification scheme of consumable ice.¹–⁶ currently, there are solutions toward process optimization, but there are still no considerable investigation regarding lowering the inlet water temperature. This research experimented a prototype box type heat exchanger to lower the inlet water temperature as this will lead to higher production efficiency. In the production process, water are circulated in the cooling tower until the tube ice reaches the specified diameter and it will go into the defrost stage. In this stage, excess cold water from the cooling tower are usually discarded as waste into a sump below the tower with the heat exchanger placed inside the sump. New water for the next production batch re-routed through the heat exchanger to lower the inlet temperature before entering the cooling tower.

Tubular ice process

From a water tank 6 meters above the floor at 28°C, water will go into production process. A selection of 10 ice-making tubes, each positioned at different points of the ice-making machine was made. They are used to collect the thickness of ice from each tube, starting at Minute 5 until Minute 35, at 5-minute intervals. The last parameter at Minute 36 would be the measurement from the discharged ice shown in Table 1

Methods

The heat exchanger design was focused on increasing the travel path of water into the Cooling tower. The heat exchanger design was optimized by curling through the lower sump to maximize the exposure distance between incoming water and cold water in the lower sump.

Designing heat exchanger

In designing a heat exchanger, we studied about the possibility and the limits of the ice making machine.

We found that the water input into the ice making machine depended on the input from a reservoir that is 6 meters above the floor. So, the equations used were 1 – 8 as following.

Hydraulic Diameter, \(D_h\):

\[D_h = \frac{4A_c}{W_p}\]  \(\ldots (1)\)

Given:

\(D_h = \text{Hydraulic Diameter, (m)}\)
\(A_c = \text{Cross-sectional Area, (m}^2\)\)
\(W_p = \text{Wetted perimeter of the duct, (m)}\)

Mass flow rate equation:
\[ \dot{m} = \rho A v \]  \hspace{1cm} \text{(2)}

Given:
\[ \dot{m} = \text{Mass flow rate, (kg/s)} \]
\[ \rho = \text{Mass density of the fluid, (kg/m}^3\text{)} \]
\[ A = \text{Section Area, (m}^2\text{)} \]
\[ v = \text{Flow velocity of the mass elements, (m/s)} \]

Volume flow rate equation:
\[ \dot{V} = Av \]  \hspace{1cm} \text{(3)}

Given: \( \dot{V} = \text{Volume flow rate, (m}^3\text{/s)} \)

Reynold Number:
\[ \text{Re} = \rho v D_h / \mu \]  \hspace{1cm} \text{(4)}

Nusselt Number:
\[ N_u = h D_h / k \]  \hspace{1cm} \text{(5)}

Empirical Correlation or Dittus-Boelter equation for turbulent flow inside a smooth tube:
\[ N_u = 0.023 \text{ Re}^{0.8} \text{ Pr}^{0.3} \]  \hspace{1cm} \text{(6)}

Thus, heat transfer coefficient can be found from:
\[ h = (k/D_h) 0.023 \text{ Re}^{0.8} \text{ Pr}^{0.3} \]  \hspace{1cm} \text{(7)}

The rate of heat transfer can be obtained from:
\[ \dot{Q} = UA \Delta T_{lm} \]  \hspace{1cm} \text{(8)}

The calculations in this research considered that heat transfer in one dimension between discharged water and inlet water to have constant values and temperature independent.

Results of heat exchanger calculation
The design gives an heat exchanger with heat transfer rate of \( \dot{Q} = 50.2 \text{ kW} \) with a length of 34 m and placed in a discharged water reservoir of dimension 1.5m x 1.5m x 0.5 m.

Experimental process
After the calculation of the heat exchanger requirement, the prototype was completed using stainless. The device was installed below the cooling tower inside the lower sump. The heat exchanger is hollow inside for inlet water to flow in. Data collection was done using an electrical analyzer placed at the power terminal. The experiment was conducted for 24 consecutive hours and the data was recorded against the first trial as there were no water in the sump.

Results and Discussion
The Comparison of Before and After the Installation of the Heat exchanger

Time and production cycle time
Considering the thickness of ice at 12mm, the time it takes before and after the installation of heat exchanger are 36.0 minutes and 33.25 minutes respectively. The 2.75 minutes reduction is the result of this device is shown Figure 1. The desired ice thickness is approximately 11.50 millimeters. With the installation of heat exchanger, the averaged
production time decreased from 36 minutes to 33.25 minutes with slight increase in ice thickness from 11.08 mm to 11.75 mm. Ice thickness is shown in Figure 3 as the heat exchanger could increase the rate of ice thickness over the same time interval.

**Electricity consumption**

Figure 2 shows the electric power of the compressor. The value of 110.14 kW or 53.50 kW-h/tons. The averaged electrical power of the compressor after the installation of heat exchanger decreased by about 1.4 kW or 0.68 kW-j/tons. The cooling load increased by approximately 10.43% and the coefficient of performance (COP) had increased 11.24%. The electrical energy can be reduced by 1.27%

**Economic analysis**

Table 2 compares the data before and after installing the heat exchanger by

<table>
<thead>
<tr>
<th>Item</th>
<th>Before</th>
<th>After</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power consumption in production process</td>
<td>92.31 kW</td>
<td>89.94 kW</td>
<td>-2.58 %</td>
</tr>
<tr>
<td>Power consumption in defrosting process</td>
<td>17.82 kW</td>
<td>18.80 kW</td>
<td>+5.21 %</td>
</tr>
<tr>
<td>Total power consumption</td>
<td>110.14 kW</td>
<td>108.7 kW</td>
<td>-1.27 %</td>
</tr>
<tr>
<td>Time of production cycle</td>
<td>2,175 sec</td>
<td>2,010 sec</td>
<td>-7.58 %</td>
</tr>
<tr>
<td>Daily Production Capacity</td>
<td>49.40 Ton</td>
<td>52.36 Ton</td>
<td>+6.00 %</td>
</tr>
<tr>
<td>Daily Electrical Consumption</td>
<td>53.50 kWh</td>
<td>52.82 kWh</td>
<td>-1.27 %</td>
</tr>
</tbody>
</table>

Table 3 — Savings made by the device and payback period

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Yearly electricity cost before the installation of heat exchanger</td>
<td>44,116 USD/y</td>
</tr>
<tr>
<td>II. Yearly electricity cost after the installation of heat exchanger</td>
<td>43,515 USD/y</td>
</tr>
<tr>
<td>III. Annual Savings</td>
<td>553 USD/m</td>
</tr>
<tr>
<td>IV. Investments</td>
<td>576 USD</td>
</tr>
<tr>
<td>V. Payback Period</td>
<td>Less than 5 months</td>
</tr>
</tbody>
</table>

Note – Electricity Charge in Thailand

The electrical energy equals 771,861.2 KWh/year and after installing the electrical energy equals 762,049.92 KWh/year. In one year the value decreases 9,811.29 KWh/year or about 1.27 percent when improving the capacity by installing the heat exchanger when the process was optimized. Table 3 shows the electricity costs within one year and payback period. The electricity costs of before and after installing the heat exchanger were 44,416 USD/y and 43,515 USD/y respectively, so it can economize about 115 USD per month and the payback period will be approximately five months. Installing the heat exchanger could be a way to increase the capacity of the production process in the ice industry very well. The payback period of five months are calculated only from electrical savings. In actuality, the profit made from higher production rate will generate even more profit. During the design considerations, a radiator could replace the box type heat exchanger for maximum efficiency.
But it is not possible in this case due to the requirement of a water pump system which will consume more energy, requires further investment and complicate to install.

Conclusion
This research had studied the performance improvement of a tube ice production machine by the installation of a box type heat exchanger at the sump under the cooling tower. The results showed that it had reduced the power consumption and increase the production capacity after the installation of a heat exchanger. The device was inexpensive and is able to be installed with any ice production machines. Therefore this device is both practical and cost effective to serve as a guideline for other existing factories.

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References