Improvement of a hot water producing system in a chili sauce

Warachit Phayom¹,* and Jakkaphan Bamrugcharoen¹

¹Energy Engineering, Faculty of Technology, Udon Thani Rajabhat University, Udon Thani, Thailand 41000

* Corresponding Author: warachit.ph@udru.ac.th

Abstract

In Udon Thani Province (Thailand), Mahachai Food is a small-sized food processor that manufactures and distributes chili sauce to the local market. The manufacturer is faced with various problems in its production facility. A significant problem was in its hot water system. The system required workers to transfer hot water by buckets. Also, its energy costs were quite high. Thus, this research aims to upgrade the manufacturer’s hot water production system. In doing so, the investigator designed vessels and LPG stoves that preheated the water by solar flat plate collectors and implemented a water transfer system using a pipe system. The results are as follows: 1) Water transfer required only one-third of the original time. This reduced the need for workers from four persons to just one. It also helped increase safety in the workplace since the potential of human exposure to hot water was greatly reduced. 2) The efficiency of the hot water producing system was increased. 3) The cost of energy-producing hot water was reduced.

Keywords: Chili Sauce Manufacturing Facility, Hot Water Production System, Improving the Performance, Thermal Efficiency, Solar flat plate collector.

1. Introduction

Udon Thani province is located in the north-east region of Thailand where its economy is growing and expanding rapidly. Udon Thani has the 3rd highest economic growth in the north-east region presently [1]. The most potential and funded industry in Udon Thani is the food industry [2]. However, most food industry is a small-sized food factory. Also, Mahachai Food (hereinafter called the ‘manufacturer’) is a small-sized food processor that manufactures and distributes chili sauce to the local market. The production capacity is approximately 10-12 cycles per month. Each cycle is produced 5000-6000 bottles of 750 milliliters (4000-4500 liters). The main ingredients of the production are chilies, flour, and hot water. The most important matter in the manufacturing process was producing hot water. There were many problems in producing hot water as follows:

1. Heating water resulted in high energy losses. The total produced hot water was approximately 4000-4500 liters per cycle. So, it required up to 80-90 kilograms of LPG gas. This was due to using ordinary cooking vessels along a single wall with no insulation. Additionally, they had no lids which increases heat loss. There were two-vessel sets for switching. The first set consisted of two 200 liters vessels and another set had one vessel of 280 liters, as can be seen in Figure 1.
Figure 1. The stoves and cooking vessels used by the manufacturer
(a) A set of two 200-liters vessels (b) A set of a 280-liter vessel

2. Each cycle, the manufacturer would boil water about 20-23 rounds. During boiling water, there was much wasted time. Waiting for enough water for every vessel before transferring material to the tank used for mixing chili sauce because boiling time caused long delays. To boil the water took approximately 35 minutes and transferring it approximately 20 minutes in each round. Because the manufacturer had 2 sets of chili sauce mixing tanks, water was transferred almost all the time.

3. The process of transferring hot water from the vessels to the chili sauce mixing tanks required four workers; 1 person for scooping hot water from the vessels into 10-liters buckets, 2 people for carrying the buckets to the chili sauce tank with a distance of about 10 meters, and another one for pouring hot water from the buckets into the chili sauce tank. In each chili sauce mixing round needs to use 150 liters of water at a temperature of 90 degrees Celsius and about 10 liters of other ingredients to fill in a 280-liter mixing tank. The worker who scooping hot water into the 3 liters of a bowl had to make about 15-20 buckets. Then the workers who carries the buckets had to finish about 10 times per round. This process was a very unsafe workplace practice. As an aside, [3] reported human skin pain receptors are located at approximately 0.1 mm depth and the pain temperature threshold is 44.8°C. A portage of hot water was very dangerous. That also slows the manufacturing process (Figure 2).

Figure 2. Manual workers were used to transferring hot water from the vessels to the chili sauce tank

These manufacturing problems contributed to energy losses and increased manufacturing expenses. Thus, to improve manufacturing capacity, this research aimed to improve the manufacturer’s hot water production system by increasing the overall thermal efficiency and alleviating the need for the manual worker, thus reducing costs and expenses for energy while improving workplace safety.
2. Materials and Methods

For this study, the plant layout of the manufacturer was improved. The original layout of the plant had a fairly distributed work area (Figure 3a) and the working area was still being used ineffectively. Besides, the distance between the boiling water area and the sauce mixing area was more than 10 meters away and the boiling water area was outdoor where there might be ruined by the sunshine, wind, and rain. Therefore, plant layouts of the machinery, water transfer system, and the water heating system equipment were designed as shown in Figure 3b.

![Figure 3](image)

Figure 3. Plant layout (unit: millimeter) (a) the original layout (b) the new layout

The details of the new system: water storage, pipelines, and pumps replaced human workers in the water transfer system. The proper location of the hot water pipelines was important. It should not obstruct the walkways used by workers. Also, it should be as short as possible to reduce heat losses. However, the pipe must not be covered so that it could be removed and easily cleaned. The stations of all equipment should be stable, durable, support their function, and maintenance. Moreover, the cooking vessels, the stoves, and the gas station would be moved to indoor and put next to the mixing sauce area. The gas stove should use low conductivity materials and insulations [4], such as refractories bricks, as much as possible. The gas stove had a width of 60 centimeters on each side and a height of 40 centimeters. Its wall was made of refractory bricks, the outside was covered with stainless steel, and the 4 pillars were made of stainless steel. Additionally, the station where gas was located should have connections for multiple tanks. The new vessels were made of stainless steel with double insulation. Their maximum safe volume was 250 liters. The chili sauce mixing tank can receive 150 liters per batch, as shown in Figure 4.

The installation of a solar water preheating system can significantly improve the system. It can help reduce fuel energy used to heat water [5, 6]. The parts of a solar water preheating system consisted of 2 flat plate solar collectors with a total net area of 2 square meters, which was a recessed 500 litre-vessel with insulation as shown in Figure 5. The solar water preheating system was designed by the water flowing from the inlet into the outlet with a series flow pattern to increase the water temperature. The flat plate solar collector was covered with transparent glass and its absorber plate which was painted black to absorb the maximum amount of solar irradiance. While the underneath and side of the collector were insulated by glass wool to decrease the heat loss by conducting through the absorber plate. Besides, pressure relief valves, pressure, and temperature gauges have been installed. It was considered stable safe, and economical.
Data was collected on both original and new systems for analysis of gas consumption ($Q_{LPG}$, kJ per day) useful energy ($Q_{useful}$, kJ per day) heat transfer rate to water within the solar collectors ($Q$, Watts) overall thermal efficiency of the system ($\eta_a$) thermal efficiency of the Flat plate solar collector ($\eta_{FP}$) breakeven analysis and payback period.

3. Results and Discussions
Examination and analysis could be divided into two parts. First, the manufacturer’s original system was examined. Then, the ability to perform or the performance of the researcher’s proposed system was determined. The following was found:

3.1 Performance of the manufacturer’s previous system
The original system required four workers, one working on transferring water into and out of the vessels, two workers transferring water from the water heating area to the chili sauce mixing tank, located 10 meters away. One worker controlled the overall manufacturing processes. Collectively, their wages were 1,200 THB per day at least (300 THB/day/person).

The manufacturer’s original process consisted of multiple processing lines, each with its vessel, gas stove, and a 48 kg gas tank. One line had a vessel with a volume of 280 liters, and the other two had volumes of 200 liters/vessel.

According to the energy analysis using LPG to heat water, it was found that the average daily volume of water heated was 4.52 cubic meters (4,520 liters). This required 83.57 kg of LPG or 4,119,831.04 kJ or 2 gas tanks a day. The useful energy transferred to the water heating system to increase the average water temperature at the initial state of 25.60°C to the average water temperature at the final state of
101.50°C or the average temperature difference (ΔT) of 75.90°C was 1,398,553.66 kJ. Overall, the thermal efficiency of the system was 34.02%.

Heat losses account for 65.98% of the energy used. On this basis, the system required 912.31 kJ per liter of water for heating for THB 0.39 per liter of hot water or THB 0.30 per bottle of chili sauce. The total daily (cycle) expenses for heating water were THB 1,778.44, representing a loss of THB 1,173.45. At the time of the analysis, the LPG price was THB 21.28 per kg [7]. Moreover, the increased temperature that the water experienced during heating was 75.90 degrees Celsius. The capacity for hot water production was only 3.89 liters per minute. See Table 1.

Table 1. Analysis of energy use in heating water with the original system

| No. | V_W (m³/day) | m_LPG (kg/day) | ΔT (°C) | Q_LPG (kJ/day) | Q_useful (kJ/day) | η_th (%) | Time (min) | Capacity (L/min) |
|-----|--------------|----------------|---------|----------------|------------------|----------|------------|-----------------|
| 1   | 4.72         | 94.19          | 79.70   | 4,643,190.24   | 1,526,369.43     | 32.87    | 1,142.00   | 4.13            |
| 2   | 4.38         | 78.86          | 75.84   | 3,887,482.56   | 1,358,465.72     | 34.94    | 1,214.00   | 3.61            |
| 3   | 4.45         | 77.67          | 72.17   | 3,828,820.32   | 1,310,825.83     | 34.24    | 1,132.00   | 3.93            |
| Avg | 4.52         | 83.57          | 75.90   | 4,119,831.04   | 1,398,553.66     | 34.02    | 1,162.67   | 3.89            |

3.2 Performance of the new design

After the hot water system was improved, only one worker was needed to control the system. The process tasks included turning valves on and off to produce the desired flow.

As shown in Table 2, it was found that only 4.02 cubic meters (4,020 liters) of water were successfully heated. This was because there were unexpected obstacles in the process. Other system components failed many times, especially in the chili sauce mixing part. Thus, the volume of heated water appears to be as small as the same process duration was needed. However, the amount of LPG gas used daily was only 45.75 kg or 2,255,292.00 kJ or only a gas tank. The total amount of energy transferred into the water to increase the average water temperature at the initial state of 25.79°C to the average water temperature at the final state of 92.28°C or the average temperature difference (ΔT) of 66.49°C was 1,060,717.92 kJ at an overall thermal efficiency of 47.12%. The new system produced 10.24 liters of hot water per minute at a daily energy cost of THB 973.56. Furthermore, the rate of gas used was 560.43 kJ per liter of water for THB 0.24 per liter. This was a 38.46% savings over the manufacturer’s original system.

Table 2. Analysis of energy use in heating water with the new system

| No. | V_W (m³/day) | m_LPG (kg/day) | ΔT (°C) | Q_LPG (kJ/day) | Q_useful (kJ/day) | η_th (%) | Time (min) | Capacity (L/min) |
|-----|--------------|----------------|---------|----------------|------------------|----------|------------|-----------------|
| 1   | 4.41         | 44.69          | 49.75   | 2,203,038.24   | 1,078,714.68     | 48.96    | 387.00     | 11.39           |
| 2   | 4.26         | 48.46          | 59.36   | 2,388,884.16   | 1,056,495.14     | 44.23    | 401.00     | 10.63           |
| 3   | 3.40         | 44.10          | 73.62   | 2,173,953.60   | 1,046,943.95     | 48.16    | 391.00     | 8.70            |
| Avg | 4.02         | 45.75          | 66.49   | 2,255,292.00   | 1,060,717.92     | 47.12    | 393.00     | 10.24           |

For the water preheating system by solar flat plate collectors, the collectors were faced with the south direction and the tilt angle of 25 degrees [8, 9]. The experiments were done during the rainy season when the solar irradiance was unlikely to be high. Figures 6 shows that the highest solar irradiance during the examination was only 586 Watts per square meter.
The average air temperature ranged from 29.53 to 34.05 degrees Celsius. The average relative humidity of air was 65.57% to 80.59%. The average wind speed varied from 0.30 to 0.53 km per hour. Examination of water mass flow rate through the flat plate collectors revealed a flow rate was 5 liters.

Figure 6. The solar irradiance and the water temperatures at the entrance and exit of the solar collectors.
per minute or 300 liters per hour. This is the rate at which warm water could flow into the receiving vessel without overflowing. It was found that the difference between inlet and outlet temperatures of water was averaged as 3.07 degrees Celsius. Furthermore, the outlet temperature of the water could be as high as 40 degrees Celsius, even when the solar irradiance was low. Heat transferred to the collectors was calculated as 1,069.6 Watts. The thermal efficiency of solar flat plate collectors was 91.26%. However, if the manufacturer needs a greater volume of warm water, it is suggested that more flat plate collectors should be installed. This is because collectors in a series connection will help increase the water temperature. Nevertheless, it should be noted that such an installation will experience an increased pressure drop within the system. To address this pressure drop [10, 11], it is suggested that the installation be made up of two flat plate collectors along with additional warm water heaters.

3.3 Break-even analysis and payback period
Break-even analysis used the principle of [12] with the straight-line method, whilst the payback period followed the one of [13, 14]. Fixed costs included depreciation costs, interest expense, salary, and shipping costs. Variable costs included costs of LPG gas, water, electricity, maintenance costs, ingredient, and packaging. The results found that the break-even point was around 240,769 bottles per year. That means, if normal production is 60,000 bottles per month, the manufacturer must produce 4 months to break-even. The energy costs related to hot water production were cut by approximately half. The original system produced water for THB 0.39 per liter while the new system reduced this to THB 0.24 per liter at a cost savings of THB 6,750 per month. The new system also reduced wages to THB 13,500 per month. Lastly, the total capital expenditure on the new system was THB 1,000,000, and it would take 49 months to reach the payback period.

4. Conclusion
The improvement of the hot water production system at this chili sauce factory increased the manufacturer’s efficiency in the following ways:

1. The newly designed hot water production system as well as the water piping and pumping system to supply the chili sauce vessel, clearly reduced the time needed for water transfer. Whilst the previous system took 20 minutes to transfer water from the vessel and then to the chili sauce mixing tank, the new system could transfer the same volume of water within 5 minutes. Furthermore, the developed system also helped to promote safety in the workplace and reduce the labor required from four workers to just one.

2. The developed hot water production system helped increase the heat efficiency of the boiler by 12.79%. Also, it helped increase the capacity for hot water production by a factor of three. It was also better in that it allowed for transfer water to the sauce mixing tank as one volume rather than in many small buckets.

3. The economic benefits from energy and labor costs when comparing before and after improvement systems were 13,500 baht per month, resulting in a payback period of 49 months. It should be noted that if the manufacturer increases its production, the variable costs will be reduced and the payback period will be sooner.

Although the manufacturer has significantly reduced the costs, the addition of a solar hot water production system can also be done. Besides, the coming automation systems or the internet of things (IoT) will help to make the operation more efficient and environmentally friendly.

Acknowledgments
This project was funded by the Thailand Research Fund (TRF): RDG6050144. The authors are grateful to Krisda Buarapa for supporting the experiments and Asst.Prof.Nutthanuch Mekara and Prof.Dr.Jeffrey C. Nash of Udon Thani Rajabhat University for their continued interest and encouragement.
5. References

[1] Marome W and Pholcharoen T 2019 *Environment Asia* 12(3) 1-11
[2] Udon Thani Industry Office, Ministry of Industry 2020
   http://www.industry.go.th/udonthani/index.php/component/k2/item/10552?rss_id=12206,
   accessed 1 December 2020
[3] Log T 2018 *Int J Environ Res Public Health* 15 808-821
[4] Nilrat M Suthummanon S and Taweekun J 2017 *NUEJ* 12(1) 115-30
[5] Bhowmik H and Amin R 2017 *Energy Rep* 3 119-23
[6] Kalogirou S A 2014 *Solar energy engineering: processes and systems* (Waltham, MA: Elsevier
   Inc.) pp 14-15
[7] Energy Policy and Planning Office, Ministry of Energy 2019 *Energy statistics of Thailand 2019*
   (Nakhon Pathom, Thailand: Energy Policy and Planning Office, Ministry of Energy) p 204
[8] Stanciu C and Stanciu D 2014 *Energ Convers Manage* 81 133-43
[9] Jamil Ahmad M and Tiwari G N 2009 *Open Renew Energ J* 2 19-24
[10] Hassan J M Abdul-Ghafour Q J and Mohammed M F 2015 *J.Eng* 21(5) 55-71
[11] Zelzouli K Guizani A Sebai R and Kerkeni C 2012 *Engineering-PRC* 4 881-93
[12] Hunt D and Wilson D 2016 *Farm power and machinery management* (Ames, Illinois: Waveland
   Press) p 212
[13] Ardalan K 2012 *JEFE* 11 10-16
[14] Umar A B 2010 *AMA-AGR MECH ASIA AF* 41(4) 82-6