Design of Heat-Cold Integration System between Thawing and Cooling of Pre-cooking Fish Processes

A. Suwatthikul, P. Kittisupakorn

Abstract— **Canned tuna is Thailand's important export product, which has grown rapidly in recent years. However, due to increasing economic pressure, global competition and environmental awareness, the industry has to constantly innovate to improve its production procedure to make it more sustainable and competitive. The aim of this work is to propose a devise of a heat-cold integration system between thawing and cooling after pre-cooking processes by introducing a multi-tube heat exchanger. The low-grade energy recovery in the thawing process is then used to transfer heat to the water of the cooling process. This leads to not only water savings but also energy savings.**

Index Terms—**Thawing, Cooling, Multi-tube heat exchanger.**

I. INTRODUCTION

Canned tuna is Thailand's important export product, which has grown rapidly in recent years to 44,863 million Baht (440,255 tons) in 2007 [4]. However, due to increasing economic pressure, global competition and environmental awareness, the industry has to constantly innovate to improve its production procedure to make it more sustainable and competitive. Efforts are needed to develop a cleaner process while maintaining the production level, improving natural resource management, and minimizing the pollutants.

Tuna canning involves the following processes: receiving and initial storage, thawing, butchering, pre-cooking, cooling, loining, canning, adding the filling media and can seaming, retorting and packaging as illustrated in Fig. 1.

This paper focuses on thawing process and cooling process.

In thawing process: frozen tuna is unloaded to the thawing tanks. Thawing by immerse the frozen blocks of fish in fresh water until they reach an optimum temperature for cutting. This temperature is generally kept below 0°C. Tuna is thawed between 30 minutes to 6 hours depending on its size [1]. Large amounts of water are use in the thawing process.

In cooling process: water was sprayed from a perforated pipe to the precooked fish to reduce its temperature. The spray cooling time is not fixed, depending on a production plan. If delays exists before cleaning, the water is sprayed continuously to the precooked fish to prevent surface dehydration. Such an approach consumes high water and of course leads to more wastewater. H-Kittikun et al.[3] reported that the spray cooling in a factory consumed only 1.1 m^3 water/ton of raw material. In addition, an improper production plan resulted in a longer spray cooling time, thus more water was consumed [7].

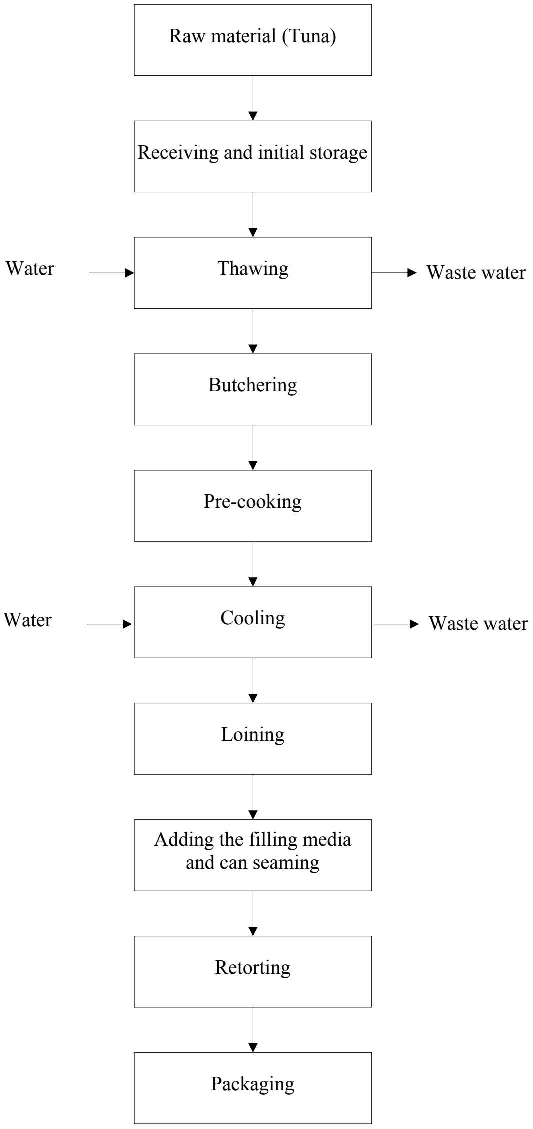

Fig. 1 Process flow diagram of tuna fish canning

The aim of this work is to propose a design of heat-cold integration system between thawing and cooling the after pre-cooking processes by implementing a heat exchanger. The heat exchanger will provide low-grade energy recovery in the thawing process. The energy is then transferred to the

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water in the cooling process. As a result, the water and energy savings are obtained.

II. DYNAMIC THAWING MODEL

Frozen fish is normally stored at 18 °C for preservation. Thawing is necessary before any subsequent fish processing or cooking. There are different thawing methods available but cold water thawing method is favorable when a short thawing time is required. In this method, frozen fish is immersed in a tank of cold water at a temperature above the melting point of the food. One can speed up the cold water thawing process by promoting force convection in the water tank to increase the convective heat transfer. Alternatively, force convection can be achieved by running water in an overflowing tank.

A schematic diagram of the thawing tank is given in Fig. 2. The thawing tank can be described mathematically by the volume and mass balance equations as follows:

$$\dot{V}_t = Q_i - Q_o \qquad (1)$$

$$\dot{m}_t = Q_i\rho_i - Q_o\rho_o \qquad (2)$$

The flow rate Q_i is the incoming, h_o is the overflow height, Q_o is the outgoing freely flows, $\boldsymbol{\rho}_{\mathrm{i}}$ and $\boldsymbol{\rho}_{\mathrm{o}}$ is the incoming and outgoing density respectively.

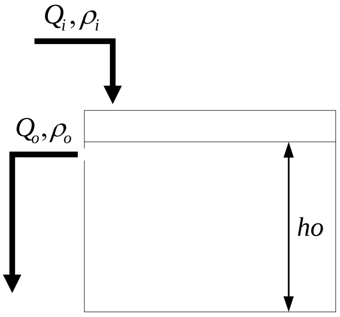


Fig. 2. The thawing tank.

A schematic diagram of system thawing process is given in Fig. 3. The pond can be described mathematically by the volume and mass balance equations as follows:

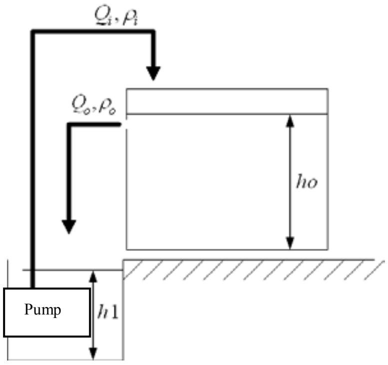


Fig. 3. System of thawing process.

$$A\frac{dh_1}{dt} = Q_o - Q_i \qquad (3)$$

$$A\rho\frac{dh_1}{dt} = Q_o\rho_o - Q_i\rho_i \qquad (4)$$

The flow rate Q_i is the outgoing, h_1 is the height of pond, Q_o is the incoming overflow from thawing tank.

III. HEAT TRANSFER EQUIPMENT

A heat exchanger is a device that is used to transfer heat between two or more fluids that are at different temperatures. In the majority of heat exchangers, a solid wall separates the two fluids so that they are not in direct contact with each other. [5]

A. Basic design procedure

The shortcut rating method for multi-tube exchangers depends on the same technique as used for shell-and-tube exchangers. The general equation for heat transfer across surface is based upon (5). [6]

$$Q = UA\Delta T_m \qquad (5)$$

For sensible heat transfer, the heat transfer rate is given by;

$$Q = \dot{m}_h C_{p,h}\left(T_{h,i} - T_{h,o}\right) = \dot{m}_c C_{p,c}\left(T_{c,o} - T_{c,i}\right) \qquad (6)$$

The prime objective in the design of an exchanger is to determine the surface area required for the specified duty (rate of heat transfer) using the temperature difference available.

The overall coefficient is the reciprocal of the overall resistance to heat transfer, which is the sum of several individual resistances. For heat exchanger across a typical heat exchanger tube the relationship between the overall coefficient and the individual coefficients, which are the reciprocals of the individual resistance, is given by

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{1}{h_{od}} + \frac{d_o ln(d_o/d_i)}{2k_w} + \frac{d_o}{d_i h_{id}} + \frac{d_o}{d_i h_i} \qquad (7)$$

The steps in a typical design of an exchanger are given below:

1) Define the duty: heat-transfer rate, fluid flow-rates, and temperatures.
2) Collect together the fluid physical properties required: density, viscosity, thermal conductivity.
3) Decide on the type of exchanger to be used.
4) Select a trial value for the overall coefficient, U.
5) Calculate the mean temperature difference, ΔT_m.
6) Calculate the area required from (3).
7) Decide the exchanger layout.
8) Calculate the individual coefficients.
9) Calculate the overall coefficient and compare with the trial value. If the calculated value differs significantly from the estimated value, substitute the calculated for the estimated value and return to step 6.
10) Calculate the exchanger pressure drop; if unsatisfactory return to steps 7 or 4 or 3, in that order of preference.

Before (5) can be used to determine the heat transfer area required for a given duty, an estimate of the mean temperature difference ΔT_m must be made. This will normally be calculated from the terminal temperature difference: the difference in the fluid temperatures at the inlet and outlet of the exchanger. The logarithmic mean temperature difference: LMTD is determined by:

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{ln[(T_1 - t_2)/(T_2 - t_1)]} \tag{8}$$

where T_1 and T_2 is inlet and outlet shell-side fluid temperature, t_1 and t_2 is inlet and outlet tube-side temperature.

The usual practice in the design of shell and tube exchangers is to estimate the “true temperature difference” from the logarithmic mean temperature by applying a correction factor to allow for the departure from true counter-current flow:

$$\Delta T_m = F_t \Delta T_{lm} \tag{9}$$

The correction factor F_t is given by Kern (1950) for the flow configuration involved is found as a function of dimensionless temperatures ratios for most flow configurations of interest

$$F_t = \frac{\sqrt{R^2+1}\, ln\left[\frac{1-S}{1-RS}\right]}{(R-1)\, ln\left[\frac{2-S\left(R+1-\sqrt{R^2+1}\right)}{2-S\left(R+1+\sqrt{R^2+1}\right)}\right]} \tag{10}$$

where R is the correction coefficient and given by:

$$R = (T_1 - T_2)/(t_2 - t_1) \tag{11}$$

and S is the efficiency and given by:

$$S = (t_2 - t_1)/(T_1 - t_1) \tag{12}$$

The heat transfer coefficient h_i can be determined from the equation of Nusselt number:

$$Nu = \frac{h_i d_e}{k_f} = 0.023 Re^{0.8} Pr^{0.33} (\mu/\mu_w)^{0.14} \tag{13}$$

Then Reynolds number and Prandtl number are determined as follows:

$$Re = \frac{\rho u_t d_i}{\mu} \tag{14}$$

$$Pr = \frac{C_p \mu}{k_f} \tag{15}$$

There are two major sources of pressure loss on the tube-side of a shell and tube exchanger: the friction loss in the tubes and the losses due to the sudden contraction and expansion and flow reversals that the fluid experiences in flow through the tube arrangement.

$$\Delta P_t = N_p \left[8 j_f \frac{L}{d_i} \left(\frac{\mu}{\mu_w}\right)^{-m} + 2.5\right] \frac{\rho u_t^2}{2} \tag{16}$$

The procedure for calculating the shell-side heat transfer coefficient for single shell pass exchanger is given below (Kern (1950) and by Ludwig (1965)):

1) Calculate the area foe cross-flow As for the hypothetical row of tubes at the shell eqrator, given by:

$$A_s = \frac{(p_t - d_o) D_s l_B}{pt} \tag{17}$$

2) Calculate the shell-side mass velocity G_s and the linear velocity u_s:

$$G_s = W_s / A_s \tag{18}$$

$$u_s = G_s / \rho \tag{19}$$

3) Calculate the shell-side equivalent diameter varies with the flow arrangements. For square tube pitch:

$$D_e = \frac{1.27}{d_o}(pt^2 - 0.785 d_o^2) \tag{20}$$

and for triangular tube pitch:

$$D_e = \frac{1.10}{d_o}(pt^2 - 0.917 d_o^2) \tag{21}$$

4) Calculate the shell-side Reynolds number by:

$$Re = \frac{G_s D_e}{\mu} \tag{22}$$

5) For the calculated Reynolds number, read the value of j_h from Fig. 4. for the selected baffle cut and tube arrangement, and calculate the shell-side hate transfer coefficient *hs* from:

$$Nu = \frac{h_s D_e}{k_f} = j_h Re Pr^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14} \tag{23}$$

Here, j_h is dimensionless thermal factor according to Kern method and can be specified from Fig. 4.

6) For the calculated shell-side Reynolds number and calculate the shell-side pressure drop from:

$$\Delta P_s = 8 j_f (D_s/d_e)(L/l_B) \frac{\rho u_s^2}{2} \left(\frac{\mu}{\mu_w}\right)^{-0.14} \tag{24}$$

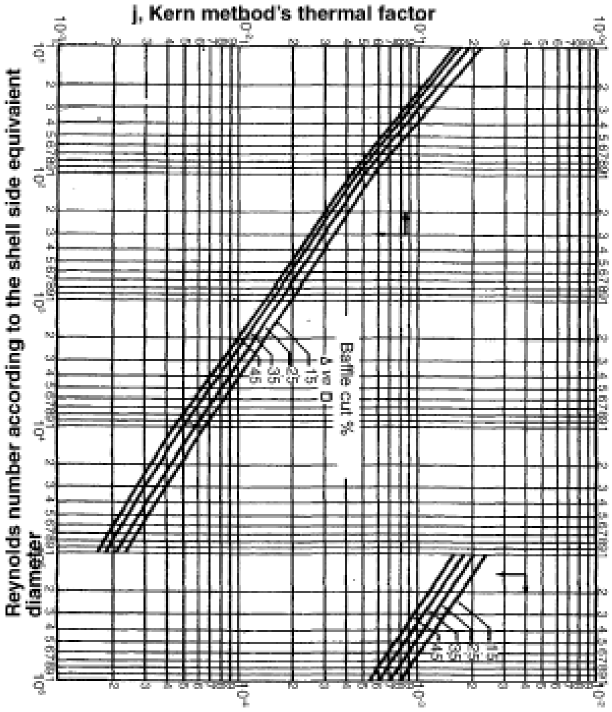
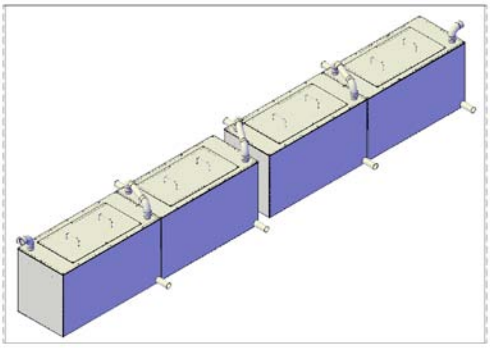


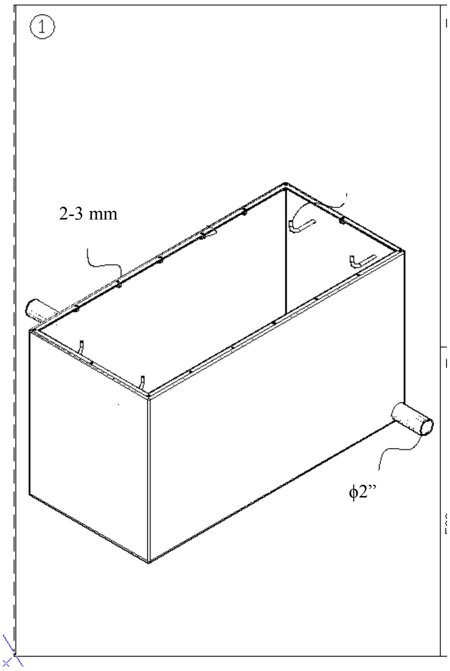
Fig. 4 Dimensionless coefficient according to Kern method vs Reynolds number according to shell side equivalent diameter.[5]

IV. RESULT

The present invention relates to a method and an apparatus for recovering heat in water and waste water by using the waste water for cooling the hot water before the hot water is supplied to the cooling process. Hot water flows through the tubes, and waste water of thawing process flows within the space between the tubes and the shell. Figure 5 shows the design multi-tube heat exchanger and its accessory which are heat exchanger housing, overall exchanger component. Multi-tube circuits are design as shown figure 6a and 6b.



(a)



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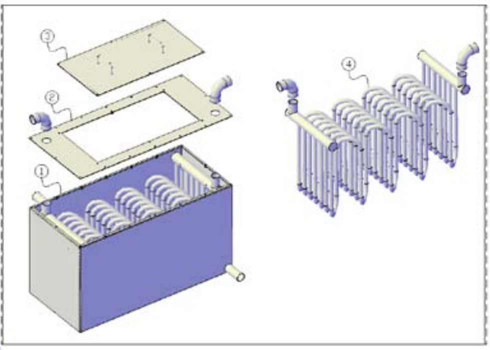
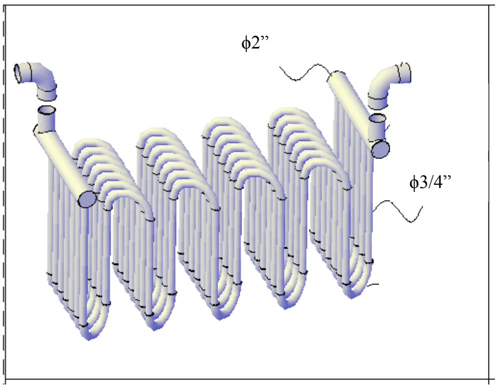
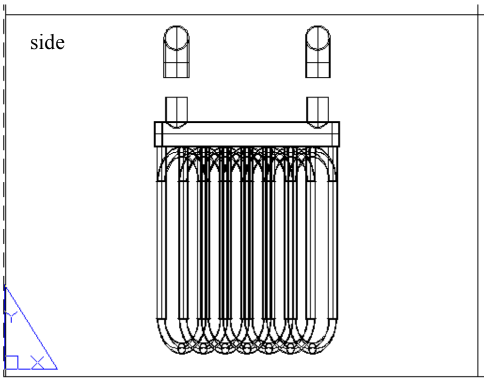


(c)

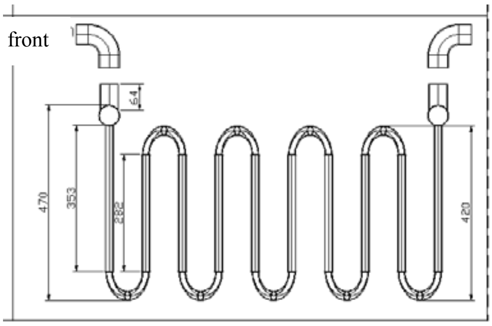


(d)

Fig. 5 (a) Multi-tube heat exchanger (b) Heat exchanger housing (c) Overall exchanger component (d) Multi-tube circuits of heat exchanger.



(a)



(b)

Fig. 6 (a) The front view of multi-tube circuits (b) The side view of multi-tube circuits.

Nomenclature

A	Heat transfer area
A_s	Cross-flow area between tubes
C_p	Specific heat
d_e	Equivalent diameter
d_i	Tube inside diameter
d_o	Tube outside diameter
D_s	Shell diameter
F_t	Logarithmic mean temperature difference

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	correction factor
G_s	Shell-side mass flow-rate per unit area
h_i	Film heat transfer coefficient inside a tube
h_{id}	Fouling coefficient on inside of tube
h_o	Heat transfer coefficient outside a tube
h_{od}	Fouling coefficient on outside of tube
h_s	Shell-side heat transfer coefficient
j_h	Heat transfer factor according to Kern method
j_f	Friction factor according to Kern method
k_f	Thermal conductivity of fluid
k_w	Thermal conductivity of tube wall material
l_B	Baffle spacing
N_p	Number of tubes
Nu	Nusselt number
$\triangle Ps$	Shell-side pressure drop
$\triangle Pt$	Shell-tube pressure drop
Pr	Prandtl number
p_t	Tube pitch
Q	Heat transfer in unit time
R	Dimensionless temperature ratio
Re	Reynolds number
S	Dimensionless temperature ratio
T	Shell side temperature
T_1	Shell side inlet temperature
T_2	Shell side exit temperature
ΔT_{lm}	Logarithmic mean temperature difference
ΔT_m	Mean temperature difference
t	Tube side temperature
t_1	Tube side inlet temperature
t_2	Tube side exit temperature
U	Overall heat transfer coefficient
U_o	Overall heat transfer coefficient based on tube outside area
u_s	Shell side fluid velocity
u_t	Tube side fluid velocity
W_s	Shell-side fluid mass flow rate
Greek letters	
μ	Dynamic viscosity
μ_w	Viscosity at wall temperature
ρ	Density
Subscripts	
c	Cold stream
e	Equivalent
h	Hot stream
i	Inlet
o	Outlet

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