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# Performance Efficiency of In-line Stirred Yoghurt Machine Modeling for Use in SMEs

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**Abstract:** A prototype in-line stirred yoghurt machine was designed and constructed for use in SME dairy plants and education establishments. The prototype consisted of mixer, pre-heater, pasteurizer, cooler, incubator and filling systems all necessary processes were aggregated within a 2.8 $m^2$ steel base. The operation of production was controlled by a set of Programmable Logic Controller (PLC) and/or one personal computer. Testing was done with a yoghurt mix. Results showed that the pasteurization system, using heat from a small gas burner transferred to the flowing raw milk through heat exchangers, destroyed all pathogenic microorganisms. Thereafter, the yoghurt mix was incubated in an insulated stainless steel tank at 42°C for 3 h, then cooled to 20-25°C over 30 min and total acidity of product was not >0.76%. Production capacity was approximately 100 cups $h^{-1}$ by one operator. Overall, it was felt the prototype offered significant advantages in terms of its small size, portability and ease of operation. The 73% energy efficiency will also offer significantly reduced production costs.

**Key words:** Yoghurt, pasteurization, incubation, shell and tube heat exchanger, energy efficiency

## INTRODUCTION

With the booming interest in small scale industrial enterprises, various types of food production have come to the forefront. Small scale industries are businesses that require few people to run and which have certain advantages over large-scale industries. Small to Medium Enterprises (SMEs) in Thailand have been supported and subsidized by the government in particular food industries. Apart from restaurants, jewelry, healthcare products, automobiles and machinery, the most profitable SMEs opportunities in Thailand are agriculture-related businesses (Ajaero, 2013) including food, beverage and dairy production for example.

Total market value of soft, drinking and culture yoghurts is growing in each country. For example, Thailand is increasing by approximately 5% each year and was worth around 2,180 MB in 2013. As there are only 3-4 manufacturers, this offers significant opportunities for small scale producers to exploit. However, the major barrier to entry for SMEs is the importation of expensive machinery.

Jitjaroen *et al.* (2008, 2011a, b) have invented a prototype in-line stirred yoghurt production machine (Fig. 1). The machine consisted of milk mixing, pasteurization and incubation systems. These were

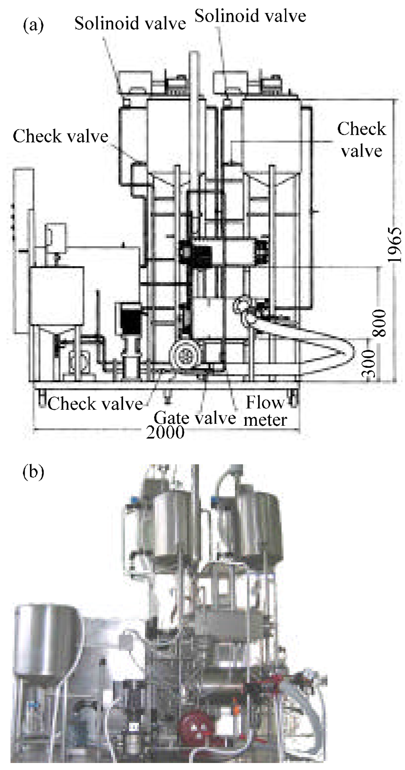


Fig. 1: A prototype in-line stirred yoghurt machine system (Jitjaroen *et al*., 2008)

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installed together on a portable-basement sized 2.8 $m^2$. After integrating the various elements of the system, they were able to cooperate continuously to make a standardized product (Jitjaroen *et al*., 2008, 2011a, b). This research evaluated the co-efficiency of mixer, pre-heater, pasteurizer, cooler and incubator for yoghurt production. The result would be established as a prototype for use in small industries, as well as educational institutes.

## MATERIALS AND METHODS

To calculate fluid flow in the tube and flat sheet, researchers used the Reynold number which is one of the factors in fluid heat exchanger theory and the Nusselt number to calculate the heat transfer coefficient (Yunus, 2002; Toledo, 1991; Holman, 1997). A prototype in-line stirred yoghurt machine system was designed and operated as shown in Fig. 2.

**Stirred yoghurt production by prototype machine:** Yoghurt ingredients were mixed in the mixing tank, pumped into the pasteurized unit and heated by hot air. The mixture temperature increased the mixture to pasteurized temperature of 72°C within 15 sec by heat exchanger with a flow rate of 806 mL $min^{-1}$ and a holding time of 67 min. After that the mixture was cooled to 40-45°C and then transferred to the incubation tank. It was incubated with a yoghurt starter for 3-4 h until it curded. The curd was stirred to a cream, together with a reduction in temperature to 20-25°C, before the packing process (Alfa-Laval Dairy and Food Engineering, 1980; Jitjaroen, 1999). Then, it was stirred for 15 min before filling into the cups. The operation system was controlled by electronics and computer.

**Designing and constructing system**

**Mixing system:** The 50 L of stainless steel No. 304 cylinder shape mixing tank consisted of 1/3 horse power (hp) motor and a paddle (Fig. 3). The ingredients (milk, sugar, stabilizer and flavoring matter) were mixed (Fig. 2; $T_1$) then flowed to the pasteurizing system.

**Pasteurization system:** The pasteurization system consisted of a forced draft burner, pre-heater and heater (Fig. 2; HE01 and HE02) and a holding tube (Fig. 2; $T_3$). The burner used for heating up the milk was connected with 2 sets of shell-and-tube heat exchangers, called pre-heater and heater.

**Pre-heater heat exchanger:** The 1 shell 8 pass stainless steel heat exchanger was constructed (Fig. 4) in order to exchange temperature between cold milk which came from the mixer and hot milk which came from the main heater in the opposite direction. These allow the hot milk to cool down before flowing to the incubator.

**Main heater heat exchange:** The 1 shell 10 pass stainless steel heat exchanger was constructed (Fig. 4). The tubes were a part of cold milk to exchange temperature with hot air from the burner. The milk was heated to pasteurization level. The data were sent to a PLC in order to adjust to an appropriate milk flow rate.

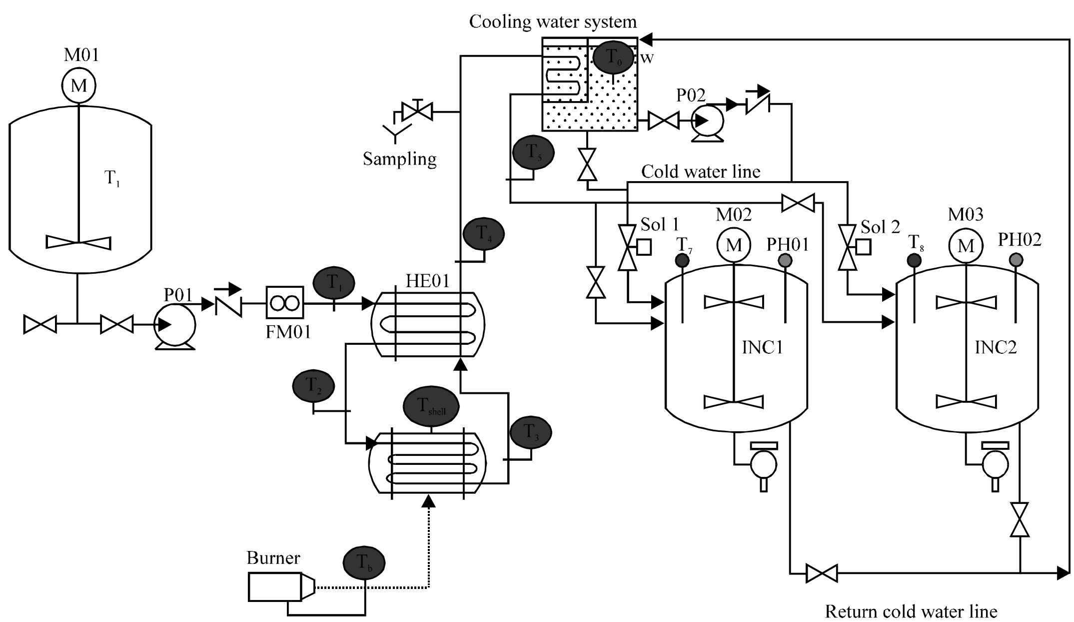


Fig. 2: Diagram of a prototype in-line stirred yoghurt machine system (Ajaero, 2013)

Fig. 3: Inner mixing tank with a paddle

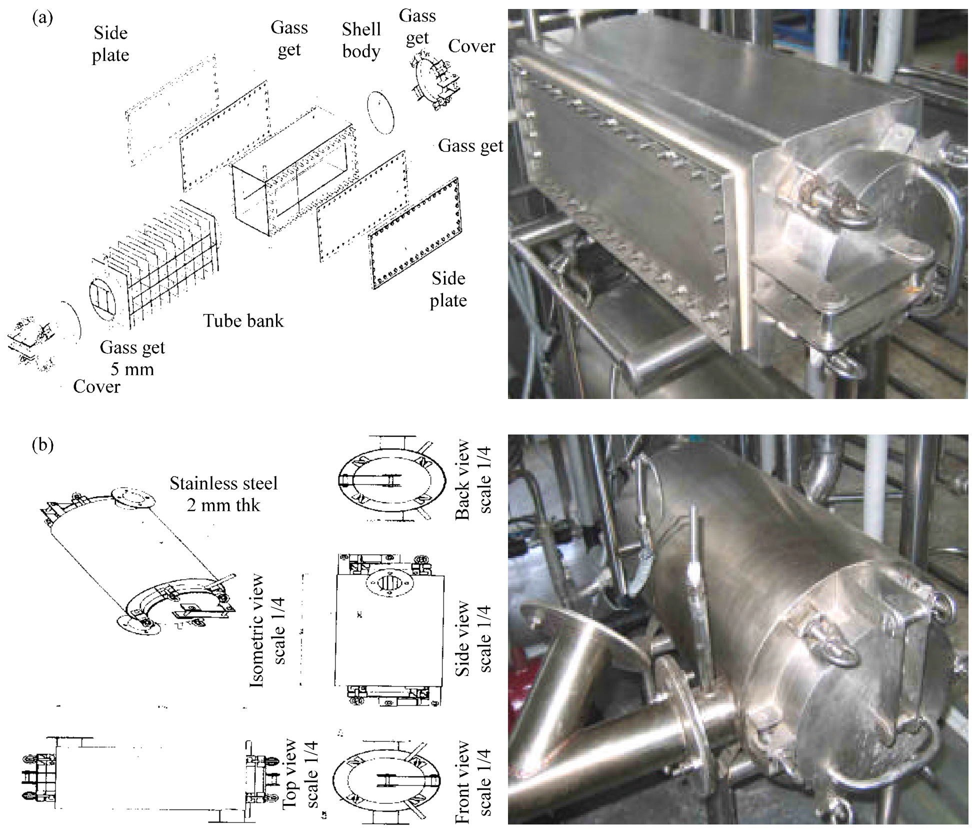


Fig. 4: Structure of the shell and tube heat exchanger: a) Pre-heater unit; b) Heater unit (Jitjaroen *et al*., 2011a)

A holding tube was used to delay the time to ensure the full pasteurizing period. The proper temperature of the milk related to the period of time holding for each particular temperature (Jitjaroen *et al*., 2008).

The efficiency of pasteurization was measured from the relationship between the proper temperature, time and the level of the enzyme phosphatase which indicates the number of microorganisms in the pasteurized milk (Yunus, 2002; Holman, 1997).

**Cooling system:** The 200 L stainless steel cooling tank, insulated with polyurethane was equipped between pasteurizing and incubating units (Fig. 5). The tank was divided into 2 sections. About 1 section was an inner set of spiral tubes, to cool the hot milk to the right incubation temperature. The other section was a cool water tub to decrease the incubated yoghurt temperature from 40-45 to 12-15°C.

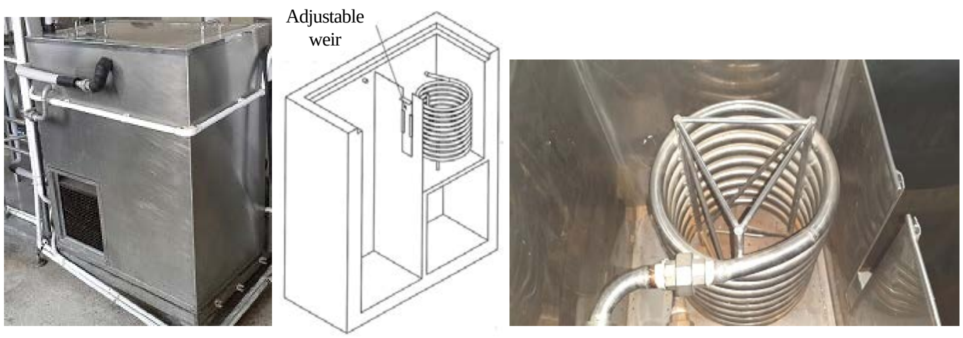


Fig. 5: Cooling tank with inner spiral tube (Jitjaroen *et al*., 2008)

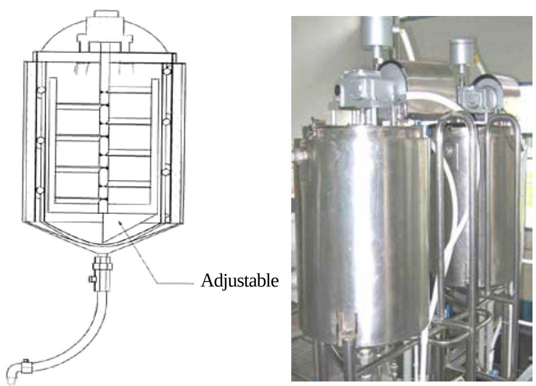


Fig. 6: Inside structure and image of incubation tank of in-line-stirred yoghurt (Jitjaroen *et al*., 2011b)

**Incubation system:** The incubation tank was designed in 3 layers of stainless steels No. 304 and was cylindrical in shape (Fig. 6). The outer layer was shielded with 1 inch thickness of polyurethane to maintain the correct temperature while in the incubation process. The middle layer was a circular channel for 1°C water. The inner layer contained pasteurized milk. The incubation tank was of 50 L capacity with a lid on top and installed with a 1/4 hp, 1:60 motor gear. The incubation tank started to drive the agitator to stir the yoghurt at 20 rpm, as well as the cold water was pumped to circulate in the middle layer, until the yoghurt temperature was reduced to 20-25°C. This indicated that the packing process could be begun (Jitjaroen *et al*., 2011a).

The efficiency of yoghurt incubation system was measured from the milk temperature while incubated in the tank and from the total acidity level while reducing the temperature of yoghurt (Alfa-Laval Dairy and Food Engineering, 1980).

**Energy efficiency testing:** The energy efficiency of the machine was studied by ratio comparison of theoretical and practical energy consumptions, both in electrical and Liquid Petroleum energy (LPG) used in the system. The energy efficiency (%) equals to the theoretical energy consumption ×100 divided by the practical energy consumption).

## RESULTS AND DISCUSSION

The in-line stirred yoghurt machine system was systematically operated and tested. In terms of engineering, the efficiency of the machine testing was examined from the capability to pasteurize yoghurt mix, heat exchange, keep the temperature of incubator steady and reduce the temperature in a given period of time.

**Efficiency of pasteurization system:** A pasteurization system prototype machine can eliminate microorganisms as expected, by monitoring the milk temperature coming into the system at different periods of time and location. Figure 7 shows that the milk has some variation of pasteurization temperature ($T_3$) within the first 5 min of the milk pumping process. Then, the temperature was gradually adjusted to balance the situation (Line B).

Milk pasteurization at temperatures higher than 72°C and flow rate of 806 mL min$^{-1}$, showed no phosphatase. This means there were no pathogenic microorganisms which are very dangerous to humans.

The main heat exchanger can exchange the heat faster than what we expected by 30%. This means the quality to increase the milk temperature was very high. On the other hand, the heat exchange rate to reduce the temperature of the milk which took place near the pre-heater unit and the temperature reducing unit before the incubation process was slower than expected. This was the reason for extending the heat exchanging area by increasing the temperature of the cold-water tank and tube inside the tank to interface more with cold water. This helps maintain the incubation temperature at 42°C.

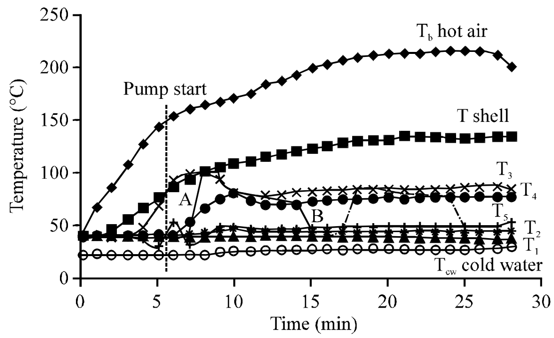


Fig. 7: Relationship between temperature and time of pasteurization ($T_1$ = 33°C, flow rate 806 mL $min^{-1}$; $T_b$ = 210°C): $T_1$ = Raw milk; $T_2$ = After preheating; $T_3$ = Pasteurization; $T_4$ = Before cooling; $T_5$ = Post colling

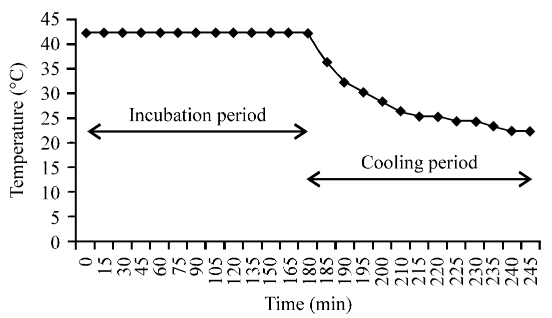


Fig. 8: Yoghurt temperature during incubation and cooling periods

However, the graph shows that the pre-heat temperature ($T_5$ post-cooling) was at approximately 42°C throughout the process. This indicated the accuracy of the pasteurization process.

**Incubation and cooling systems efficiency:** The efficiency of the incubation tank testing was examined from the capability to keep the temperature of the yoghurt steady and to reduce temperature in a given period of time by measuring the temperature at the centre of the tank every 15 min.

Figure 8 shows the temperature throughout the incubation for 3-4 h was around 42°C constantly and cooling periods were able to reduce the temperature of the yoghurt to lower than 25°C in an hour with constant 0.76% of total acidity. This indicated that the incubation tank shield was sufficient to keep the temperature steady and yoghurt temperature reducing process was as effective as expected.

**Energy efficiency:** The energy efficiency of the machine was studied in terms of electrical current and LPG used for the whole operation. The theoretical and practical energy necessary to supply per one batch production of 50 L were 27,336 and 37,397 kJ, respectively. The energy efficiency was high at a level of 73.09%.

## CONCLUSION

The prototype machine can produce stirred yoghurt from raw milk as designed and constructed. It was controlled by a PLC. The prototype machine can pasteurize the milk within a given period of time, cool the pasteurized milk to qualify for the incubation process, keep the temperature in the tank steady while incubation process until the milk curded and reduce the temperature of yoghurt before packing. The stirred yoghurt reached the necessary biochemical standard and the prototype machine can be used in the yoghurt milk pasteurization industry.

Production capacity was approximately 50 L per batch, 300-600 cups by 1 operator within 5 h, depending on the number of incubators which can be added. The prototype offers significant advantages in terms of its small size, portability and ease of operation. The 73% energy efficiency will also offer significantly reduced production costs.


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