Economic analysis of heat pump integrated icecream making plant

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ABSTRACT: Worldwide icecream is considered favorite dessert and its consumption is increasing day by day. Icecream manufacturing comprises of processes like pasteurization, homogenization, chilling of mix, and freezing. Around 65°–70°C of temperature is required for pasteurization which is achieved by using hot water generated by electricity or gas or other fuels. Around 1°C chilled water is required to be supplied by refrigeration for cooling the icecream mix. Aging of this mix is to be done for 5–6 h in aging tank at 4°C and then it is taken to the freezer to produce icecream. Also, icecream plant requires large amount of hot water for cleaning and sanitizing the equipments, piping, utensils and washing floors. As in icecream manufacturing process, both heating and cooling are required; the use of heat-pump may prove to be a better solution. In this paper, detailed economic analysis has been given for heat pump integrated icecream making plant. The aim of process integration is to reduce the energy consumption and, thereby, the operating cost of the icecream making. Heating and cooling requirement for 2,000 L of icecream production per day has been calculated. Suitable heat pump has been integrated to the existing plant in order to have benefit of heating utility for partial pasteurization upto temperature 58°C and cooling utility for the partial cooling of mix upto temperature 18°C. Saving of around 34% of energy consumption is made by the heat pump integrated systems. As per the calculations, simple payback period for modified icecream making plant with heat pump is just 2.2 years.

1. INTRODUCTION

Study of energy saving in an industrial process using heat pump integration begins with the collection of data, finding out the scope of its integration in existing system and finally, the modifying the system. Heat pump is widely used in domestic applications like space heating in cold countries. Use of heat pump in industry is very advantageous if both heating and cooling utilities are required in the process. A.H. Zaidi et al. (1979), in their study, explained the use of heat pump in dairy industry. They integrated heat pump system with pasteurizers, evaporators, spray dryers, refrigeration, and cold storage equipment which are used in the dairy plant.

Icecream making is one such process where simultaneous heating and cooling are required. After studying the flow diagram of the existing process, it was found that there are certain areas where integration of heat pump is possible to some extent for pasteurization, cooling, aging and in freezing. Also, icecream industry requires lot of hot water for cleaning and sanitizing utensils, and washing the shop floor. This requirement can also be fulfilled by heat pump. J. Ubbels and S. Bouman (1979) studied the opportunities of saving of energy in milk cooling and heating water in farms. They showed integration of heat pump in refrigerated farm tank with the use of precooler, and explained the conservation of energy analytically and experimentally where water is being heated with a heat pump. Pasteurization is a process which is used in dairy and icecream industry requires heat energy. Thermal and economic analysis of heat pump and auxiliary heater for the use of milk pasteurization process is carried out on heat transfer basis and the life cycle cost of system is evaluated. Omer omakli et al. [Soylemez M.S.] studied water source heat pump integrated in the existing system and experiments were carried out for variation in COP with time at certain temperatures. In this paper, an icecream mix plant of 500 L/h capacity is taken as a case study and energy conserved by integrating heat pump to the existing set up is calculated. A new process flow diagram is also generated. Economic analysis of the project is carried out to ensure its viability considering 2000L/d of icecream production.

Nomenclature

m	Mass flow rate, (*kg/s*)	Q	Load, (*kW*)
ΔT	Temperature difference, (*°C*)	PHE	Plate heat exchanger
Cp	Specific heat, (*kJ/kg.K*)	COP	Coefficient of performance

2 PROCESS INTEGRATION METHODOLOGY

1.1 *Introduction to case study*

The industrial process that is used for this analysis is an icecream mix manufacturing unit of 500 L/h capacity with total production 2000L/d of icecream. Here, it may be noted that 1 L icecream mix can produce 2 L of icecream considering overrun of 100%.

1.2 *Process operation and parameters*

The process operation steps in a conventional ice-cream making plant are summarized in Figure 1.

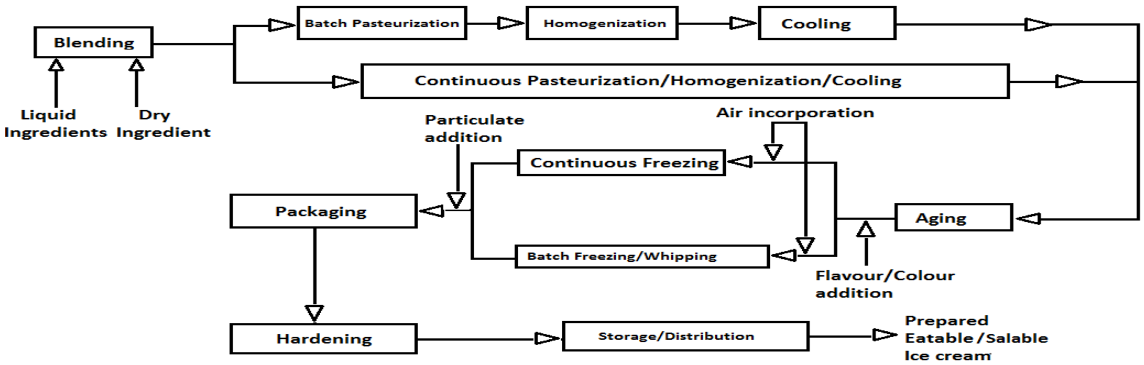

Figure 1. Process description

For the case study, an existing ice-cream making plant with following details have been considered.

Table 1. Details of existing icecream making plant

Process	Equipment	Capacity (L/h)	Operating temperature (°C)
Pasteurization	Pasteurizer, Electric heater	500	20° to 70°
Homogenization	Homogenizer	500	70°
Cooling	P.H.E	500	70° to 8°
Aging	Aging tank	1000	8° to 4°
Storage	Aging tank	1000	4°
Icecream production	Continues freezer	400	4° to -5°
Cleaning	Pasteurizer	500	30° to 60°

As the capacity of pasteurizer, homogenizer and P.H.E is 500 L, two batches of icecream mix are required for the production of 2000 L icecream per day.

1.3 *Process flow diagrams:*

The actual process diagram of existing plant is shown in Figure 2(a). Heat pump is used to generate hot water of 60°C and cold water of 10°C. Hot and cold water are stored in its respective insulated tanks. Hot water is used for partial heating of icecream mix upto 58°C for pasteurization process. Thus, the use of electric heater is reduced for pasteurization process. Cold water is used for the second stage cooling in P.H.E to cool icecream mix upto 18°C. The modified process flow diagram with heat pump is shown in Figure 2(b). The hot water required for cleaning purpose is drawn directly from hot water storage tanks.

1.4 *Analytical calculation of energy usage*

Heating and cooling requirement for each process is worked out using following equation:

$$Q = m \text{ x } C_p \text{ x } \Delta T \qquad [1]$$

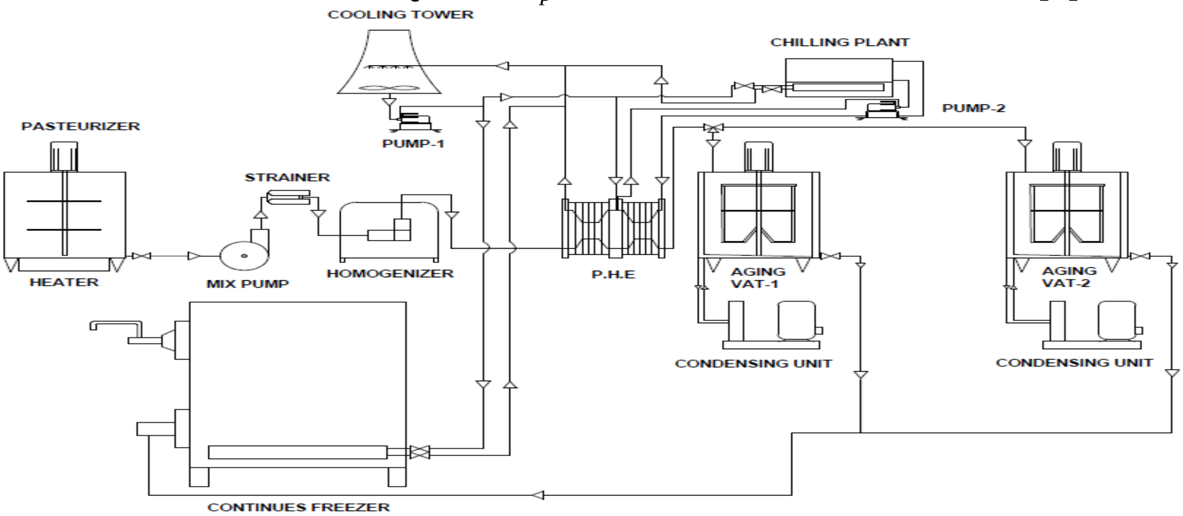

Figure 2(a). Existing icecream making plant

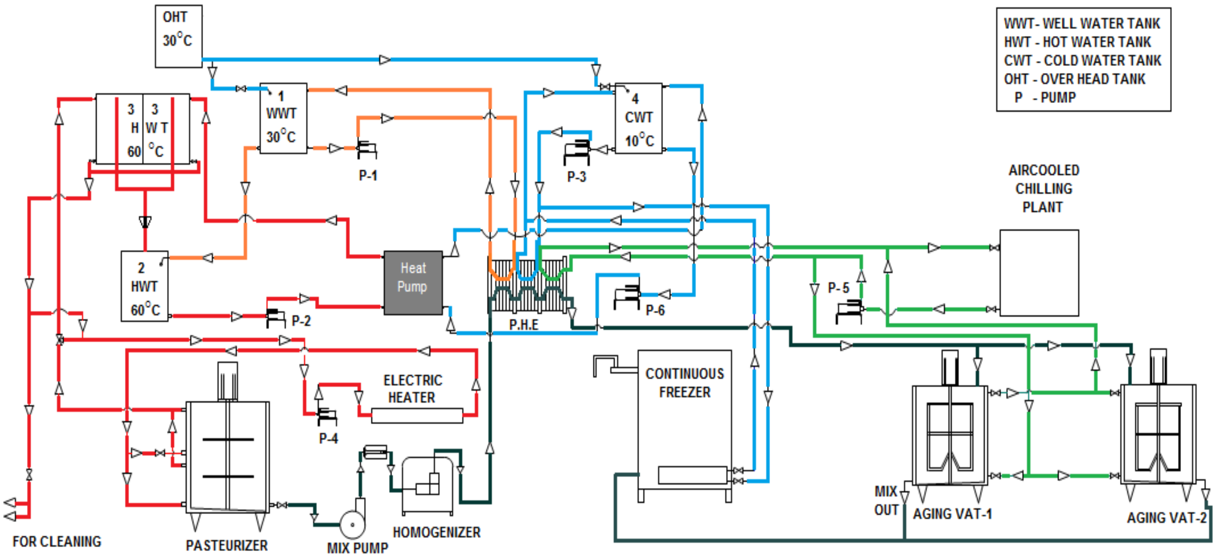

Figure 2(b). Heat pump integrated icecream making plant

The electricity required for heating is worked out using the [1]. While electricity required for other equipment is worked out considering rated motor capacity with 0.8 as load factor. C.O.P of the whole system cannot be worked out but Danfoss compressor selection charts are used to work out C.O.P of each refrigeration system. Density of water, icecream mix and frozen icecream is taken as 1, 3.31 and 2.72 kJ/kg.K, respectively. Tables 2(a) and 2(b) show the calculation of existing and modified systems, respectively, to manufacture 2000 L/d icecream.

Table 2(a). Electric energy requirement of existing plant

Equipment	Rating (kW)	Multiplication factor	Load factor	Load (kW)	Runtime (h)	Total load (kWh)
Pasteurization	16.70	1:1	-	16.70	3	50.1
Water heating (Cleaning)	17.41	1:1	-	17.41	4	69.64
Homogenizer	3.75	1:1	0.8	3	2	6
Glycol compressor	18.2*	1:2.64 **	-	6.89	2	13.78
Aging compressor (Aging)	5.02*	1:1.92 **	-	2.61	2	5.22
Aging compressor (Storage)	0.44*	1:1.92 **	-	0.22	18	4.12
Continues freezer Compressor	12.15*	1:1.62 **	-	7.5	5.5	41.25

Continues freezer dasher	3.75	1:1	0.8	3	5.5	16.5
Continues freezer mix pump	0.75	1:1	0.8	0.6	5.5	3.3
Mix Pump	0.75	1:1	0.8	0.6	2	1.2
Pump-1	0.75	1:1	0.8	0.6	7.5	4.5
Pump-2	0.75	1:1	0.8	0.6	2	1.2
Pasteurizer Agitator	0.37	1:1	0.8	0.3	4	1.2
Aging Vat Agitator	0.36	1:1	0.8	0.28	20	5.6
Cooling tower fan motor	0.27	1:1	0.8	0.21	7.5	1.62
Aging condenser fan	0.27	1:1	0.8	0.21	18	3.88
Exhaust fan	2.25	1:1	0.8	1.8	10	18
Fresh air fan	3.75	1:1	0.8	3	10	30
					Total	**277.11**

Table 2(b). Electric energy requirement of modified plant

Equipment	Rating (kW)	Multiplication factor	Load factor	Load (kW)	Runtime (h)	Total load (kWh)
Electric heater	18.11	1:1	-	-	0.66	11.95
Heat pump	12.36*	1:2.32 **	-	5.32	7.5	39.9
Homogenizer	3.75	1:1	0.8	3	2	6
Glycol PHE compressor	5.35*	1:1.73 **	-	3.09	2	6.18
Glycol aging compressor (Aging)	5.48*	1:1.73 **	-	3.16	2	6.32
Glycol aging compressor (Storage)	0.44*	1:1.73 **	-	0.25	18	4.5
Continues freezer compressor	12.15*	1:1.62 **	-	7.5	5.5	41.25
Continues freezer dasher	3.75	1:1	0.8	3	5.5	16.5
Continues freezer mix pump	0.75	1:1	0.8	0.6	5.5	3.3
Mix Pump	0.75	1:1	0.8	0.6	2	1.2
Pump-1	0.75	1:1	0.8	0.6	2	1.2
Pump-2	0.75	1:1	0.8	0.6	7.5	4.5
Pump-3	0.37	1:1	0.8	0.3	7.5	2.25
Pump-4	0.75	1:1	0.8	0.6	7.5	4.5
Pump-5	0.37	1:1	0.8	0.3	20	6
Pump-6	0.75	1:1	0.8	0.6	7.5	4.5
Pasteurizer Agitator	0.37	1:1	0.8	0.3	4	1.2
Aging Vat Agitator	0.36	1:1	0.8	0.28	20	5.6
Glycol condenser fan	0.27	1:1	0.8	0.21	20	4.32
Exhaust fan	1.5	1:1	0.8	1.2	10	12
					Total	**183.17**

*Refrigeration kW

**C.O.P of refrigeration system

2 ECONOMIC ANALYSIS OF 500L/H CAPACITY ICECREAM MIX PLANT – A CASE STUDY:

By comparing Table 2(a) and Table 2(b), it has been found that total saving of energy in modified system is 93.94 kWh. By comparing Fig.2 (a) and Fig.2 (b) it is seen that the modified system has additional equipments like heat pump, 4 insulated tanks and additional 4 water pumps while cooling tower is eliminated. Parameters are considered in economic analysis has been given in Table 3.

Table 3. Parameter for icecream plant

Items	Rating
Capacity of icecream mix plant (L/h)	500
Capacity of icecream production (L/D)	2000
Electricity used in existing plant (kWh)	277.11
Electricity used in modified plant (kWh)	183.17
Electricity saved (kWh/D)	93.94
Rate of electricity (Rs/kWh)	8
Assumed working days	250
Total saving in electricity (Rs)	1,87,880
Cost of additional equipments (Rs)	4,12,000
Additional cost for maintenance (Rs)	20,600
Total saving (Rs)	1,67,280
Life of system (Year)	10
Discount rated (%)	20
Depreciation (%)	10

4 RESULT AND DISCUSSION:

Based on parameters discussed above, the following factors are calculated and shown in Table-4 [Motwani K.H., Jain S.V., Patel R.N]. Each factor plays an important role in judging the viability of the project. Internal rate of return is coming as 38% which is more than the assumed discount rate 20%. Hence, modified project is techno-economically viable.

Table 4. Economic analysis of 500 L/h plant

Sr no.	Factor	Value
1	% Saving in Energy	33.8
2	Simple payback period (Year)	2.46
3	Net present value (Rs)	2,89,316
4	Annual life cycle cost (Rs)	1,18,871
5	Life cycle cost (Rs)	4,98,364
6	Depreciation amount (Rs)	41,200
7	Revised investment cost (Rs)	3,70,800
8	Revised net present value (Rs)	4,95,316
9	Revised simple payback period (Year)	2.21
10	Benefit to cost ratio	2.12
11	Internal rate of return (%)	38

REFERENCES:

Danfoss commercial compressor selection chart, www.commercialcompressors.danfoss.com

Motwani K.H., Jain S.V., Patel R.N., 2012, Cost Analysis of Pump as Turbine for Pico Hydropower Plants-a Case Study, NUiCONE

Soylemez M.S., 2005, Optimum heat pump in milk pasteurizing for dairy, Journal of Food Engineering, Volume 74546-551.

Ubbels J., Bouman S., The saving of energy when cooling milk and heating water on farms, International Journal of Refrigeration, Volume 2, Issue 1, January 1979, 11-16.

Zaidi A.H., Rawal S.R., Sarma S.C., 1979, Applications of Heat Pump in Dairy Industries, Indian Dairyman, Volume 31, Issue 5303-309.