Energy saving in potato processing by effective usage of environmental conditions

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Abstract

The energy consumption used in a potato processing plant with various unit operations was measured. For the water blancher, the energy required per mass of raw potato ranged between 0.50 and 0.89 MJ/kg. Since the energy efficiency of the blancher was found to be between 21 and 34%, considerable steam escaped from the blancher. A pre-cooler designed to use natural cool air was most effective to decrease the refrigeration load. Some of the energy used for frozen storage of the finished products could be reduced by seasonal coldness for several months of the year. Therefore, winter coldness was used in appropriate climates for saving energy spent to produce the frozen foods.

Key words: Energy saving, Potato processing, Blancher, Precooler.

Introduction

Since vegetables have high moisture content and short shelf life, most of them are processed at their growing district.

Food procesing after harvest is mainly concentrated in the winter season in the northern part of Japan. The increased cost of energy, decreasing availability of fossil oils, and the energy intensive characteristic of the industry have caused concern to food processors. Food processors are, therefore, searching for alternative energy sources and methods for reducing energy use. Energy consumption in the food industry accounted for approximately 12 % of the total energy use in Japan[9]. Since there were few papers on energy utilization in food processing, energy analysis was carried out on a potato processing plant in both 1985 and 1986. In this plant, energy saving in the cooling process to produce frozen food was attempted by introducing cold environmental air. The aims of this study were to determine a thermal energy balance for a water blancher and to measure the effect of substituting natural cold air as a cooling medium for pre-cooling. Furthermore, the evaluation of plant location is made by judging from electric power and fuel consumption in this plant. Information obtained from the energy analysis can be used for quantifying energy conservation practices.

Materials and Methods

Lines of frozen potato products

Investigation was conducted at a potato processing plant which is located in the

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suburbs of Obihiro as an example of frozen food production in Hokkaido, Japan. The plant processed 80 tons of raw potatoes per day. Yield of finished products obtained from 100 kg of potatoes was about 50 kg which included 40 kg of French fries and 10 kg of diced potatoes. In the frozen French fry process, raw potatoes (*Solanum tuberosum* L., var. Toyoshiro) are washed, peeled, sorted and cut into the desired shape. They are blanched in water at about 90 ℃, and then dehydrated to a moisture content of approximately 60 % (w.b.) with hot air to achieve a crisp texture in the finished French fries. The potato strips are fried in palm oil at 170℃, cooled in ambient air and frozen in an electrically operated freezer. Finally, frozen French fries are packaged and stored in a refrigerator (process A in Fig. 1.). Other frozen by-products such as diced potatoes are produced using undersized materials from process A and follow process B in Fig. 1. The water blancher was a cylinder through which product was conveyed by a turning screw, and its diameter and length were 0.8 m and 3.0 m, respectively. The screw was turned by a single moter 0.75 kW at the dischaege end. The blancher was

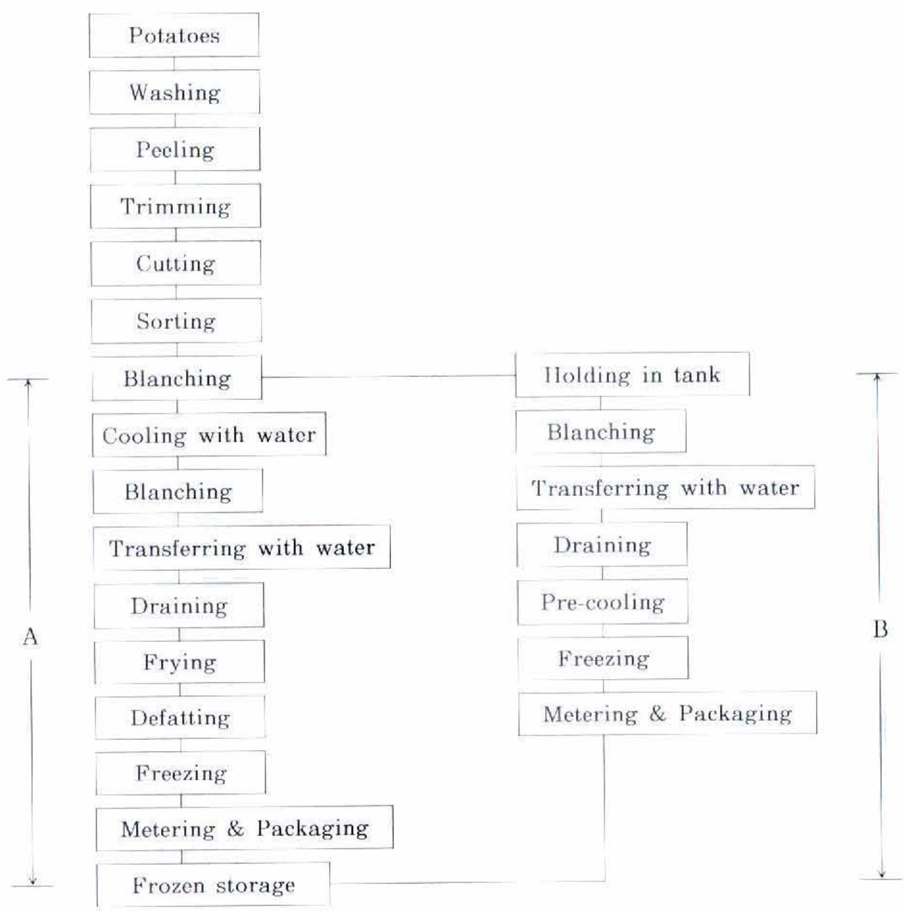

Fig. 1. Flow chart in a potato processing plant.
A and B represent French fries process and diced potatoes process, respectively.

fed by pumping product with water over a hydrosieve. Product passed from the sieve into the blancher.

At the outlet, product was discharged from the blancher onto a screen by a paddle which turned on the screw conveyer shaft.

As shown in Fig. 2, a pre-cooler designed to introduce natural cool air was installed in between the blancher and freezer. In 1986, an inverter was equipped with electric circuit of the pre-cooler to save power consumption. The pre-cooler consisted of a net conveyer, air ducts with axial flow fans and a vibrator shaker. In these processes, the energy intensive operations are associated with peeler, blancher, fryer and freezer.

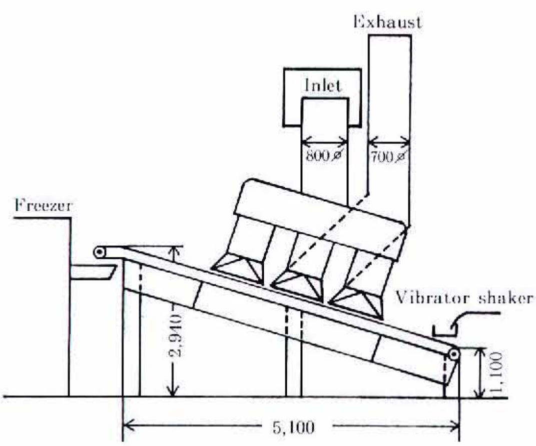

Fig. 2. Pre-cooler schematic.

Mass and steam flows

Although mass flow rate of diced potatoes was based on final packaged weight of product, that of French fries was identified by the plant record. Steam consumption by the blancher was measured by a steam meter installed in its line.

Temperature

The data logging system was composed of sensors, a data logger and personal computers. Analog data from sensors were transformed into digital values in the data logger. The digital data were transported to the personal computer by way of a RS 232C communication channel which connected the computer and the data logger. Temperatures of room air, water in the blancher and the conduit, blancher surface, and inlet and exhaust air of the pre-cooler were measured using a copper-constantan thermocouple attached to an electric data-logger with a scan interval of 1 min. These data on the diskette were then transferred to another personal computer and processed. Product temperatures in each process were determined by collecting samples in a plastic container, and inserting a metal thermometer into the center of the sample.

Powar consumption and product quality

An electric power meter which consisted of a digital printer and two clamps was used to monitor electric power consumed by the pre-cooler. It was installed in the circuit breaker. Chemical analyses of samples taken from production lines were done by AOAC method[1]. Comparison of sample means was carried out as described by Steel and Torrie[13].

Results and Discussion

Product temperature and time required in potato processing

Changes in product temperature and time required in each process are summarized in Tables 1 and 2, respectively. The product temperature after blanching remained above 70℃ in both French fries and diced potatoes. The blanching time for French fries was longer becouse the size of French frise was much larger than that of diced potatoes. As the product after blanching was transferred with hot water in the conduit, the tempe-

Table 1. Changes in product temperature (℃)

No.	Date	Blancher		Conduit		Fryer		Defatter	Pre-cooler		Freezer	
		before	after	before	after	before	after		before	after	before	after
Diced potatoes												
1	Aug. 25	27.0	69.3	69.7	64.9	—	—	—	54.0	23.8	—	−26.2
2	Aug. 26	27.8	74.3	67.9	69.3	—	—	—	55.7	24.8	—	−18.6
4	Oct. 28	28.6	84.4	81.7	76.0	—	—	—	66.5	13.3	—	−24.2
5	Nov. 12	25.3	77.4	72.2	65.4	—	—	—	55.5	8.7	—	−27.3
6	Nov. 25	26.1	79.9	77.4	72.6	—	—	—	61.6	7.5	—	−25.4
7	Dec. 6	25.8	80.4	77.7	71.5	—	—	—	59.3	9.6	—	−26.4
8	Dec. 12	22.6	82.5	79.8	73.6	—	—	—	65.8	12.5	—	−23.2
French fried potatoes												
1	Aug. 25	23.2	78.4	—	—	52.6	92.4	—	79.7	37.4	—	−20.2
2	Aug. 26	23.2	78.6	—	—	57.1	92.0	—	—	—	—	−24.9
3	Oct. 15	22.8	82.3	—	73.0	61.1	94.5	89.0	—	—	87.3	—
4	Oct. 28	23.5	86.7	—	77.0	64.2	96.2	86.2	—	—	86.4	—
5	Nov. 12	26.5	83.3	—	74.4	58.1	90.1	82.5	—	—	80.0	—
6	Nov. 25	29.2	86.1	—	78.9	66.3	96.3	90.1	—	—	87.1	—
7	Dec. 6	25.6	84.9	—	76.4	67.5	96.3	87.7	—	—	87.1	—
8	Dec. 12	29.1	85.5	—	71.9	63.2	96.2	89.1	72.4	31.2	30.9	

Table 2. Time required in each process (min.)

No.	Blancher	Conduit	Dewatering	Fryer	Defatter	Pre-cooler	Beltconveyer	Freezer	Total
Diced potatoes									
1	2.75	0.28	—	—	—	3.26	—	8.48	14.77
4	2.5	0.32	—	—	—	3.17	—	5.72	11.78
5	3.27	0.32	—	—	—	3.38	—	—	—
7	3.67	0.30	—	—	—	3.25	—	10.24	17.46
8	3.55	0.25	—	—	—	3.30	—	9.75	16.85
French fried potetoes									
1	4.56	0.56	0.48	2.18	0.40	3.26	0.38	22.36	34.18
3	5.63	0.23	0.37	2.82	0.50	—	0.38	19.73	29.66
5	5.35	0.30	0.38	2.50	0.38	—	0.42	19.97	29.30
7	5.43	0.27	0.40	2.28	0.40	—	0.42	23.75	32.95
8	5.55	0.23	0.40	2.27	0.42	3.30	0.42	20.23	32.82

rature depression of the product was very small. If no pre-cooler between fryer and freezer is used, the product having a temperature above 80 ℃ may be placed in the freezer. Therefore, the freezer has to remove a large amount of heat from the product. However, by passing through a pre-cooler product temperatures were brought within a range of 7 to 25℃ for diced potatoes, and 31 to 37 ℃ for French fries. Products were cooled mainly by forced air evaporative cooling.

Energy balance for blancher

The water in the blancher was heated by means of a silent steam injector which includes a temperature controller. The steam pressure used for injection was between 3 and 4 kg／㎠ in 1985, but was changed to about 0.9kg／㎠ using an additional pressure gauge in 1986. Although thermal and electric energies were used for blanching, electric energy consumption was quite low. As shown in Table 3, the energy effciency for water blancher was from 21 to 34% in 1986, compared to the result of 17 to 26% in 1985.

Table 3. Energy effeciency for water blancher

Year	Energy efficiency (%)	Unit energy (MJ／kg)
1985	17~26	0.80~1.50
1986	21~34	0.50~0.89

To blanch 1 kg of raw potatoes required from 0.50 to 0.89 MJ in 1986. These values for the water blancher were close to the results reported by Chhinnan et al.[6], Rumsey et al.[10] and Scott et al.[11]. A considerable fraction (60–70%) of thermal energy input escaped from the water surface (Earle 1966[8]). In addition, the energy loss through surface convection and radiation amounted to about 4% of supplied thermal energy. Therefore, design improvement such as insulation of the blancher surface is needed to minimize the energy loss.

Energy balance and cooling capacity for pre-cooler

When air is used to cool the products, cooling effluent is eliminated. Since much of the cooling is provided by evaporation of water, the yield after air cooling will be less than that after water cooling[4]. Fig. 3 shows heat balance of the blanching process. Assu-

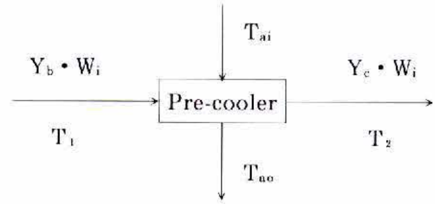

Fig. 3. Heat balance eor cooling (T_{ai} and T_{ao} are the inlet and outlet air temperatures, respectively and Y_c the yield of cooled vegetables).

ming that the products are cooled by only evaporation of water[3], the energy balance using data of diced potatoes No. 8 shown in Table 1 is given by:

$$\frac{W_e}{W_i} = \frac{Y_b \cdot C\ (T_1 - T_2)}{H} = 0.074Y_b$$

where Wi = feed rate of raw vegetables at blancher inlet (10^3kg／h), W_e = water evaporated from vegetables (10^3 kg／h), Y_b = yield of blanched vegetable (% of raw vegetable weight), C = heat capacity of vegetables (kJ／kg·℃), T_1 = temperature of blanched vegetables (℃), T_2 = temperature of cooled vegetables (℃), H = heat of vaporization for water (kJ／kg).

Water blanching may result in lower weight loss than steam blanching[2, 5]. Taking Y_b = 100%, evaporative air cooling gives a 7.4% reduction in the yield of diced potatoes. As most frozen vegetables are sold from total weight, these lower yields amount to expensive losses of production. These losses can be partially prevented by spraying the vegetables with water or blancher condensate. Table 4 indicates the seasonal changes in cooling capacity and power consumption of the pre-cooler. Less electric power for the pre-cooler could be required to cool the product in the winter season. If the pre-cooler is used in the French fry processing line, the product load for the freezer will decrease.

Table 4. Cooling capacity for pre-cooler

Product	Date	Outdoor air temp. (℃)	Room temp. (℃)	Enthalpy of materials before pre-cooling (MJ/h)	Cooling capacity (MJ/h)	Power consumption (MJ/h)
French fried potatoes	Aug. 25	29.57	24.70	193.85	102.88	28.80
	Dec. 12	5.33	17.54	141.13	80.31	46.24
Diced potatoes	Aug. 25	24.70	24.70	131.34	73.45	23.69
	Dec. 12	5.33	17.54	128.26	103.90	46.24

Effect of various operations on quality of potato products

Chemical composition of raw potatoes and products are shown in Table 5. Moisture content of the French fries was clearly lower than that of the raw potatoes, because the frying and defatting process resulted in moisture losses. As both products had less protein and ash contents compared to those of raw potatoes, it was considered that solids loss from the product occurred during blanching. Table 6 indicates statistical

Table 5. Chemical compositions of raw materials and products (%)

Item	Moisture content	Crude fat*	Protein*	Ash*
Raw material	78.23	0.05 (0.22)	2.16 (9.93)	0.91 (4.18)
Diced potatoes	78.01	0.05 (0.22)	1.72 (7.82)	0.60 (2.74)
French fried potatoes	71.74	3.57 (12.64)	2.12 (7.48)	0.69 (2.44)

Item	Pre-cooler (Moisture content)		Defatter (Crude fat)*	
	before	after	before	after
Diced potatoes	79.87	77.99	—	
French fried potatoes	70.94	69.04	3.94 (13.46)	3.51 (11.71)

* Numbers in parentheses indicate % of dry material

Table 6. Statistical difference in "t" test caluculated from data of Table 5

	Before and after defatter	Before and after pre-cooler		Between raw material and product	
	French fried potatoes	Diced potatoes	French fried potatoes	Diced potatoes	French fried potatoes
Moisture content		**	NS	NS	**
Crude fat	**	—	NS	NS	**
Ash		—	—	**	**

**: Signnificant at $P<0.01$.

NS: Not significant.

differences in "t" test calculated from data of Table 5.

Moisture content differences between inlet and outlet of pre-cooler were statistically significant. Significant defferences were seen in crude fat of French fries before and after the defatter. Since excess fat adhering to the French fries was removed, the product load for the freezer could be small.

Utilization of waste heat

Energy analysis in food processing plants has been reported by Davis et al.[7]. They indicated that waste heat in the boiler stack gas and the fryer vent was 10% and 18% of the total energy used in potato processing plants, respectively. They also found that 24% of the plant energy use was identified as waste heat from the refrigeration condensers. Recovery of waste heat from condensers would require interception of the hot refrigerant before its reaching the evaporative condenser. Utilization of waste heat in potato processing plant can occur at many points. Pre-heating of water for boiler and blancher, dryer supply air or heating potatoes before process are some possible applications. Heat pump may be an effective method for the recovery of waste heat with low energy density.

Evaluation of plant location in food processing

Monthly energy use (fuel plus power) and production data were obtained from the plant. Frozen potato products such as French fries, diced potatoes and potato puffs are produced from October through May. Carrots and sweet corn are processed from June to September. Table 7 shows the relationship between frozen food production and its unit energy from January of 1985 to November of 1986. Fuel oil was used to generate steam in the boiler and for heating oil in the fryer. Electric energy was consumed in the plant for lighting and to operate pumps, conveyers, fans and other processing equipment. Average temperature from May to September in Obihiro is 15.3℃, corresponding to the yearly average temperature in Tokyo[12]. From Table 7, it is clear that average electric intensity in Obihiro was less compared to that of Tokyo in frozen food production. For thermal energy derived from fuel oil, the energy intensity was almost the same value in both locations. Therefore, the frozen food industry in cold region should take advantage of its natural resource, that is cold weather.

Table 7. Production and unit energy in a potato processing plant

Date		Amount (kg)	Unit energy (MJ/kg)	
			Fuel	Electric power
1985 –	Jan.	1,048,601	4.97	4.62
	Feb.	1,206,181	4.41	4.06
	Mar.	1,113,704	4.78	4.77
	Apr.	1,116,829	5.87	4.92
	May	1,323,726	4.49	4.65
	Jun.	760,519	3.37	5.91
	Jul.	–	–	–
	Aug.	682,366	3.68	8.71
	Sep.	637,992	4.93	9.45
	Oct.	1,425,964	3.69	4.68
	Nov.	1,208,641	4.32	5.02
	Dec.	1,195,558	4.60	4.68
1986 –	Jan.	1,196,398	4.78	5.02
	Feb.	1,356,657	4.85	4.15
	Mar.	1,295,526	6.35	4.68
	Apr.	1,284,823	6.67	4.71
	May	1,063,810	6.63	5.66
	Jun.	–	–	–
	Jul.	–	–	–
	Aug.	567,034	3.45	9.45
	Sep.	413,985	6.83	16.18
	Oct.	1,557,243	3.69	4.40
	Nov.	1,397,032	3.92	4.43
Average		1,092,624	4.81	6.00

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バレイショの加工における
立地条件と省エネルギー

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摘 要

バレイショを主原料とする冷凍食品製造工程を対象に，その所要エネルギーを調査した。ブランチャーの加温に用いていた蒸気の温調弁を微圧のものに改め，エネルギー効率を高めたことから，ブランチングに要するエネルギーは原料1kg当り0.50〜0.89MJとそれまでの約50%に減少した。外気導入予冷機は凍結機の負荷を軽減する上で極めて有効であった。全工程の電力と燃料原単位の季節変動から，冷凍食品工場の寒冷地に立地することの有利であることがわかった。

キーワード：省エネルギー，バレイショの加工，ブランチャー，予冷機