ESTIMATING ENERGY CONSUMPTION IN SURIMI PROCESSING

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ABSTRACT

Documented power consumption rates for individual food processing operations are applied to surimi processing, freezing, and cold storage. Electrical power consumption is predicted to be 314 and 272 kWh/t (285 and 247 kWh/ton) for representative surimi plants in Oregon and Alaska, respectively, during summer operation. The influencing factors for each operation are identified.

INTRODUCTION

Surimi is a minced, washed protein product to which cryoprotectants (typically an 8% sugar/sorbitol mixture) have been added to control degradation in long-term frozen storage. It is this storage stability that is one of the important surimi properties, enabling subsequent processing to occur at a uniform rate. A second important property is that surimi forms a firm gel when thawed, mixed with about 3% salt, and heated. Gelling during various extrusion processes can produce the shape and texture of fish muscle. The addition of colors and flavors leads to the production of such seafood analogs as shrimp, crab and scallops.

The U.S. consumption of surimi-based products has grown dramatically in the last few years. Many U.S. companies are now producing the analog products that were once imported from Japan, where they were produced largely of surimi made from Alaskan pollock.

Within the last 10 years, a few demonstration projects have been initiated to produce frozen surimi in the United States. The largest in scale was managed by the Alaskan Fisheries Development Foundation and housed in the Alaska Pacific Seafoods plant in Kodiak (AFDF, 1984; 1987). This project demonstrated the ability to produce good quality surimi in a shore-based plant and supported the adaptation of technological change to what were traditional Japanese machines and processes. There are currently four shore-based Alaskan surimi plants plus a number of processing operations aboard U.S. factory ships.

More recently, attention has been focused on other geographic areas and fish species which would support U.S. surimi production. For example, Pacific whiting (Merluccius productus) represents a West Coast resource having an annual sustainable yield on the order of 175 000 metric tons (193,000 tons). Beale and Jensen (1989) reported that shore-based production on the West Coast is feasible, although "infrastructure" needs relating to land, utilities, cold storage capacity, and waste handling are major considerations.

Processors considering the production of surimi need reliable estimates of production costs. An important component of these costs is energy consumption. Therefore, energy consumption in surimi production was calculated, based on observation of an Alaskan demonstration project, on measurements at the Oregon State University Seafoods Laboratory, and on documented energy consumption for similar processes.

APPROACH

The term "surimi production" is meant to include the following operations:

On-shore processing. This includes fishing vessel off-loading, in-plant processing machinery, and wash-water chilling;

Freezing. Horizontal plate freezers are considered in the example calculations;

Cold storage. This is commercial storage of surimi blocks prior to final analog production.

Energy consumption was separately calculated for each of these three operations. Significant amounts of energy are also consumed in the following related operations which were not considered in the calculations.

1. Catching fish. Lorentzen (1981), considering both direct and primary energy costs, reported that catching used 66% of the energy required to produce frozen fillets from trawl-caught fish (the other operations being processing, 16%; transport, 12%; and distribution, 6%). Watanabe (1983) went further to show that "catching" could involve fully 70-90% of the total energy to produce the gelled analog products.
2. Refrigeration of product at sea. Documentation and summary of these direct energy costs were presented by Kolbe (1988, 1989).
3. Plant overhead, to include lights, heating, ventilating, and air conditioning.
4. Effluent treatment. This also can be a very significant cost in terms of direct energy. Watanabe et al. (1982) and H. Watanabe (personal communication) gave figures for electrical energy required to operate pumps, blowers, and presses in an activated sludge waste treatment system for one Japanese surimi plant. Waste treatment was about 120 kWh/t (109 kWh/ton) – about four times the electrical energy required for surimi processing at that plant.

Article was submitted for publication in July 1989; reviewed and approved for publication by the Food and Process Engineering Inst. of ASAE in December 1989. Presented as ASAE Paper No. 88-6593.

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This report estimates direct electrical energy consumed at the plant (kWh/t) on the basis of metric tons of frozen surimi produced. The analysis does not consider primary energy which includes "fossil fuel equivalence" of electric power generation and energy costs to manufacture machinery, chemical ingredients, and packaging. (Fossil fuel equivalence relates to the overall efficiency of producing electric power from the combustion of fossil fuels. Singh, 1984, gives this efficiency as 32.5%; Watanabe, 1985, uses a value of 43%.)

Specific energy consumption is influenced by the production capacity of the plant. Selection of a representative plant size resulted from reports and projections of AFDF (1987), Holmes and Riley (1987), Surimi Inc. (undated), Hilderbrand (1986), Talley (1986), Sonu (1986), and Anon. (1988a):

Whole fish landed	=	10 t/hr (11 tons/hr)
	=	150 t/da (165 tons/da)
Surimi yield	=	20%

Energy consumed by the freezing and cold storage operations were estimated from documented consumption rates for similar processes. In-plant processing predictions were based on the February 1985 surimi processing line set up at the Alaska Pacific Seafoods (APS) Plant as a demonstration project supported by the Alaska Fisheries Development Foundation. Figure 1 describes the process layout; each block represents a separate energy-drawing operation. The equipment was basically traditional Japanese technology; its production capacity was representative of typical Japanese surimi plants (Sonu, 1986). Although measurement of energy consumption was not part of their experimental plan, the plant was open for inspection and information retrieval, enabling us to make an estimate of energy use.

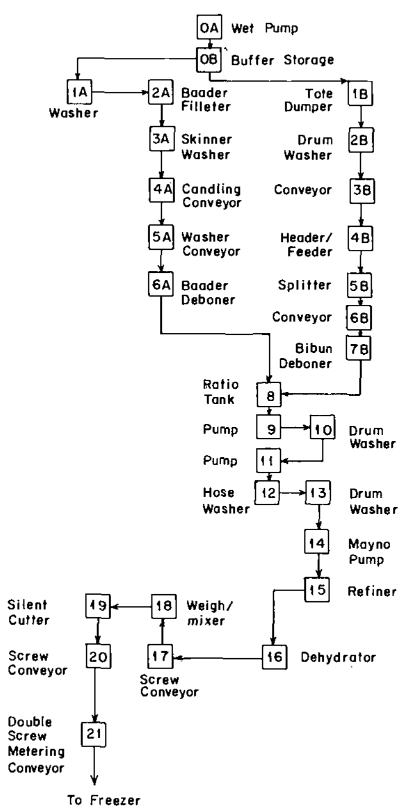

Figure 1–Alaska Pacific Seafoods surimi process in February 1985.

Direct measurement of power consumption by each machine was not possible at the time of the demonstration program. Instead, estimates were obtained by comparison with similar equipment performance and by use of nameplate data. For example measurements described by Singh (1986) showed that drive motors for pumps, agitators, and blenders in a batch yogurt manufacturing process operated close to full load. For our case, after making assumptions about load, calculation of consumed electrical power corresponded roughly to the rated mechanical power divided by electric motor efficiencies. NEMA (1977) and Baumeister and Marks (1967) give expected motor efficiencies as a function of motor size and percent rated load.

We also measured energy consumed in four major batch surimi operations set up at the Oregon State University Seafoods Laboratory. These operations included a deboner (mincer), strainer, screwpress/dehydrator, and mixer. Data provided information on percent load and representative values of specific power consumed.

Results and Discussion

In-Plant Processing

The electric power consumption of each machine in the APS line (fig. 1) is listed in Table 1. Some machines were driven by hydraulic motors. In those cases, a corrected electric power term shown in the right hand column was calculated to account for the additional losses occurring in the hydraulic power chain. Hydraulic pump and system efficiencies were taken as 85% and 75%, respectively, as recommended by Womack (1967).

"Buffer Storage" (operation OB) refers to a refrigerated room assumed to hold 1-1/2 days' raw fish production, in this scenario. Room loading density was based on guidelines presented by Myers (1981). Energy calculations followed procedures of Poulsen and Jensen (1978) .

Surimi production in temperate climates would also consume energy for wash water refrigeration. Surimi can begin premature gelation during processing if its temperature becomes too high. For cold water species like Alaskan pollock, it is recommended that product be maintained at a temperature less than 10° C (50° F, Lee, 1984; 1986). (AFDF, 1984, recommended a maximum product temperature of 4.5 ° C or 40.1° F). To maintain a 10° C (50° F) product temperature, wash water must be reduced to 5° C (41° F) or lower (Takeko, 1974; Surimi Inc., undated) from an initial temperature which will depend strongly on location. In the 1985 APS/Kodiak project, fresh water refrigeration was considered unnecessary. However, for an example location at Newport, Oregon, spring-time fresh water temperatures average 11-13° C (52-56° F) and can reach 20-21° C (68-70° F) in the summer (City of Newport water treatment plant manager, personal communication).

The volume of wash water required depends somewhat on the process. Surimi, Inc. (undated) recommended 5-6 tons of wash water for each ton of surimi produced. Sonu (1986) reported that the early "brute approach" of batch

TABLE 1. Energy consumed in APS process, February 1985*

Code	Operation	Model	Name-plate power (kW)	Assumed full load %	Electric power per unit surimi (kWh/ t)†	Corrected power per unit surimi (kWh/ t)†
Main branch into plant						
OA	Wet pump	Ryan	21	90	3.2	3.2
OB	Buffer storage				0.6	0 6
Branch #1						
1A	Washer	Baader 182 washer	0 29	80	.3	3
2A	Filleter	Baader 182	7	100	9.7	9.7
3A	Skinning machine	Baader	2 2	100	3.1	3.1
4A	Conveyer/candling		0.94	100	1.3	1.3
5A	Conveyer/washer		0.9	100	1.3	1 3
6A	Deboner	Baader 695	4.4	40	2 4	2.4
Branch #2						
1B	Tote dumper		0.06	100	0.1	0 1
2B	Lg. drum washer	Ryan	1 5	100	2.1	3 0
3B	Conveyer		0.33	100	0 5	0 6
4B	Feeder/header	Ryan 609	2 6	100	3 6	5 2
5B	Splitter	Toyo	2 6	100	3 6	5 2
6B	Conveyer		0.5	100	0 7	1 0
7B	Deboner	Bibun SDX16	4.4	75	4.6	6 6
Branch #3						
8	Ratio tank	Flohr	0 33	100	0 2	0 2
9	Pump	Crepaco R4R	1 9	75	1 0	1 4
10	Drum washer	Ryan RR300	0 75	80	0.4	0 4
11	Pump	Crepaco R4R	2.85	80	1.6	2.3
12	Hose washer					
13	Drum washer	Ryan RR300	0.75	80	0 4	0 4
14	Pump	Moyno form LE	2 1	80	1 2	1.2
15	Refiner	Fukoku RE 300	22 5	100	15 6	22.3
16	Dehydrator	Fukoku HX450	4.5	100	3.1	4.5
17	Screw conveyer		0.25	75	0.1	0.2
18	Weighing machine	Ryan (Bibun)	0 25	75	0.1	0 2
19	Mixer	Bibun BM230	22	70	10 7	10 7
20	Screw conveyer	Ryan	0 25	75	0 I	0 2
21	Filling machine	Bibun SF-15	2 57	100	1 8	1.8
Total			109.7		77.3	89 1

* Assumed overall yield = 20%
Round weight into Branch 1 = 3.6 t/ hr (4 ton/ hr)
Round weight into Branch 2 = 3.6 t/ hr (4 ton/ hr).
Efficiency of hydraulic motors = 0 7.
† 1 kWh/ t = 0 9 kWh/ ton.

washing required 30-40 times as much wash water as surimi; however, with fresh fish and newer continuous washing systems, the Japanese Surimi Association reported a chilled wash-water-to-surimi ratio of about 25 (Table 2). (This figure accounted for about 75% of the water required for the process. The balance was presumably used for fish washing, cleanup, refrigeration condenser cooling, etc.). AFDF (1984) projected a ratio of 18.

The energy required to chill water was calculated based on the performance of commercial refrigeration equipment and chillers. An example for a flow-through system (i.e., wash water dumped after use) yielded a specific energy

TABLE 2. Water consumption in four Japanese surimi plants (Sonu, 1986)

Plant	Raw matl	Surimi produced	Tap water	Chilled water		Total water
	(t/ da)*	(t/ da)*	(t/ da)*	t/ da)*	(t/ t surimi)*	(t/ t surimi)*
A		7.2	10	30-40	4.2-5.6	5.6-6.9
B		10	100	200	20	30
C	10		20	60	24†	32†
D		5	20-30	90-100	18-20	22-26

* 1 t = 1.1 ton
† Assumes overall plant yield of 25%.

cost of 42.6 kWh/t_{surimi} (38.7 kWh/ton) under the following conditions:

Freshwater inlet temperature	=	16° C (60 ° F)
Chilled water temperature	=	5° C (41° F)
Surimi production capacity	=	1.5t/hr (1.65 tons/hr)
Ratio of chilled water to surimi	=	15

The summary of results for the example scenarios and for 16° C wash water temperature follows:

Off-loading	3.2 kWh/t_{surimi} (2.9 kWh/ton)
In-plant processing	85.9 kWh/t_{surimi}(78.1 kWh/ton)
Wash water chill	42.6 kWh/t_{surimi} (38.7 kWh/ton)

Although the in-plant process total of 85.9 kWh/t (78.1 kWh/ton) was higher than the figure of 67 kWh/t (60.1 kWh/ton) projected by AFDF (1984), estimated electric power consumed by deboner, refiner, dehydrator, and mixer operations (36.5 kWh/t or 33.2 kWh/ton) compares reasonably well with a figure of 40.5 kWh/t (36.8 kWh/ton) measured at the Oregon State University Seafoods Laboratory. The difference was related in part to a difference in scale.

The single greatest influence upon direct power consumption was the refrigeration required to chill wash water. This would vary with water supply temperatures. It could be lowered by water recycling, use of heat exchangers to prechill inlet water with waste water, and new processes currently under study to reduce the required volume of wash water.

Calculations of energy to refrigerate buffer storage assumed use of a 0° C (32° F) chill room. One alternative, using tanks of refrigerated seawater, would greatly increase the power consumption for that operation.

Power for washing, refining, and dewatering would vary with new operations designed to replace or complement these traditional Japanese processes. Examples are the use of a decanter centrifuge to improve yields (Anon., 1987; Swafford et al., 1985) and application of a fruit pulper to the refining operation (Anon., 1988b).

Freezing

Table 3 summarizes a search of the literature describing specific energy required for food freezing. Except where noted, all values represent measured or observed energy consumption accountable to the freezing of a unit mass of food. The results cover a large range, 50-597 kWh/t (46-543 kWh/ton). The low value represents a case measured by Woltersdorf (1982) for freezing of beef quarters at high temperature (-18° C or -0.4° F) to conserve energy. Some of the high values appear to represent data collected during low production. Including a baseline energy cost at periods of low production can indicate a relatively high specific energy (kWh/t) as shown by figure 2 (Pedersen and Nicholson, 1983; Watanabe et al., 1982; and Rao, 1986).

Freezing of surimi or minced fish in uniformly-shaped cartons occurs most efficiently in a plate freezer. The recommendations of Graham (1984) were chosen for calculating unit energy for surimi in plate freezers. He reported the general experience ("rule of thumb") that 117 kcal of refrigeration capacity is required for each kilogram

TABLE 3. Food freezing energy use -- documented experience

Product	Freezer type	Energy (kWh/ t)*	Reference	Notes
Surimi	Plate	200	Watanabe et al. (1982)	†
Food (general)	–	90-150	Jul (1984)	‡
Chopped meat	–	131	Grolee (1982)	
Pollock fillets	Plate	71	CIRTA (1981)	§
Peas	Fluidized bed	120	Londahl (1978)	
Fish	Plate	117	Graham (1984)	‖
Beef sausage	–	88	Judge et al (1981)	
Seafood	Blast	385	Pedersen & Nicholson (1983)	#
Seafood	Brine	95	Pedersen & Nicholson (1983)	
Lean beef quarters	Blast	50-92	Woltersdorf (1982)	**
Food	–	150	Livsmedelsteknik (1980)	
Boxed meat	Blast-tunnel	104	Poulsen (1986)	††
Boxed meat	Blast-spiral	100	Poulsen (1986)	††
Peas	Fluidized bed	125	Poulsen (1986)	††
Chicken	Blast	92	Poulsen (1986)	††
Prepared food in trays	Blast	125	Poulsen (1986)	‡‡
Poultry	Blast @ –40 ° C	495	Adolfson (1982)	
Ice cream	–	597	Adolfson (1982)	
Citrus juice	Blast	161	Adolfson (1982)	
Fish	Blast	219	Adolfson (1982)	
Specialty products	–	215	Adolfson (1982)	

* 1 kWh/ t = 9 kWh/ ton
† Average figure which may include some chilling of water.
‡ Includes findings of several researchers.
§ Based primarily on calculations.
‖ Calculations based on measured values
\# One plant - probably low production.
** Energy range varied as blast air temperature was adjusted from –18 to –35 ° C (–0.4 ° to –31 ° F).
†† Oberservations for initial product temperature of 10° C (50 ° F); ammonia refrigeration equipment; saturated suction temperature of –43 ° C (–45.4 ° F); product load of 1000 kg/hr (2200 lbm/ hr)
‡‡ Same as note ††, except that initial product temperature was 40 ° C (104 ° F)

(or 211 Btu/lbm) of fillets frozen in 50 mm (2 in.) trays. This is approximately 50% greater than the enthalpy change for a typical seafood product frozen from +10° to -30° C (+50°to -22° F). Some reasons for this excess include:

- heat leaking into the freezer during operation;
- added heat capacity of frames and structure;
- down-time/losses during a load change or frost removal.

Calculations using Graham's rule of thumb gave specific energy values for both a small, single freezer system, and a large, two-stage refrigeration system freezing 45 metric tons (49.5 tons) per day. For both cases, specific energy was about 118 kWh/t (107.3 kWh/ton).

Some factors which will influence the projected energy consumption rate include:

Utilization factor. Calculations have assumed freezers are full; partial loading will lead to higher specific energy costs.

Heat leakage during freezing. Both room temperature and size (surface:volume ratio) will play a minor role.

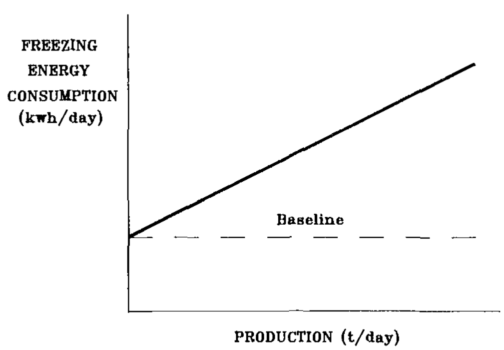

Figure 2–Expected freezing energy rate vs. production rate.

Defrost schedule.

Saturated suction temperature. Increasing this value will lower energy cost, increase freezing time, decrease utilization of freezer, and possibly decrease product quality.

Freezer design. Influences include operation with a single vs. two-stage system, use of an intercooler, type of refrigerant used, amount of subcooling and superheating, value of saturated discharge (condenser) temperature, and number of plates operated per system.

COLD STORAGE

Table 4 summarizes documented energy intensity (kWh/t) for cold storage rooms. Documented energy charged to "cold storage" is an elusive value, and it is for several reasons that the table shows such a variation in results:

1. Energy figures involve primarily the refrigeration needed to absorb heat leakage from the warm ambient. If, through mismanagement, the equipment also works to remove heat from new product that is inadequately chilled in the freezer, the energy indicated for the "cold store" operation will be uncharacteristically high.
2. Cold storage energy is directly proportional to the time in storage; thus a column listing (kWh/t-mo) has been added to Table 4 for those situations in which storage time and tonnage are known. When product is continuously moved into and out of the cold store, some mean storage time must be chosen as the basis for calculation.
3. Cold storage energy varies with the temperature difference between that of the room and that of the outside ambient. Some average ambient temperature is often omitted in the documented figures.
4. Efficiency (or coefficient of performance) of the

TABLE 4. Energy used in the cold storage of food
(Values measured, unless noted)

Product	Total energy consumed (kWh/ t)*	Period	Unit energy consumed (kWh/ t-mo)*	Reference	Notes
Kamaboko	240	---	---	Watanabe (1985)	†
Kamaboko	170	---	---	Watanabe (1985)	†
-----	200	---	---	Livsmedelsteknik (1980)	
-----	250-310	150 da	50-62	Jul (1984)	††
-----	511	1 yr	43	FAO (1977)	§
Fish	108	3 mo	36	CIRTA (1981)	
Raw meat	96	30 da	96	Judge et al. (1981)	‖
Chopped meat	36	1 mo	36	Grolee (1982)	
Peas (retail bulk)	580	---	---	Londahl (1978)	#
Peas	50	165 da	9	Londahl (1978)	**
Peas	30	46 da	31	Londahl (1978)	††
-----	57-570	1 yr	5-50	Londahl (1978)	‡‡

* 1 kWh/ t = 9 kWh/ ton
† Energy data recorded over unspecified period It includes largely "chilled" storage plus some "cold" storage of raw surimi.
‡ Jul's reference actually gave "310-250 "
§ This is a calculated value and assumes: 35 kW machinery operates 50% of the time; a 500 t (550 ton) capacity room is utilized at 60% capacity.
‖ Some "fossil-fuel equivalent" energy may have been used for electrical energy listed in a later section of this reference The value used here is assumed to be direct electrical energy.
\# Bulk retail storage.
** Bulk storage
†† Wholesale storage.
‡‡ Original data given in units of (kWh/m^3) Conversion was made assuming room to be 60% full of pallets loaded with fish blocks having a stowage rate of 1.7 m^3/t (54 6 ft^3 / ton; Graham, 1984).

refrigeration equipment decreases substantially as the room temperature decreases. Not all documented cases report even the room temperature value.

5. Size of the store room is significant, particularly at a level of 15 000 m^3 (530,000 ft^3) or less (Poulsen and Jensen, 1978). As room size falls below this value, the surface-to-volume ratio increase begins to have significance.
6. Many secondary factors will affect energy use in the cold-store. These include power rating and number of fans used in room circulation and evaporator cooling; installation of two-stage vs. single-stage refrigeration machinery; refrigerant used; condenser performance; insulation and floor construction details; defrost and operating schedule; construction of doors and openings which will influence air infiltration, and worker activity relating to lighting, machinery, door openings.

Figure 3 displays calculated results of energy consumption vs room temperature and size based on work by Poulsen and Jensen (1978), Borbely (1979), Borbely and Poulsen (1979, 1980), and Poulsen (1986). Some assumptions other than those specified in the figures are:

- Boundary insulation is 150 mm (5.9 in.) of polyurethane foam;
- The period of use is a 40-hour work-week, with lighting load and room infiltration losses calculated as shown in the references.

Calculation of a specific energy figure charged to the cold storage operation must assume a range of conditions that strongly influence the results. The following conditions were assumed for specific energy predictions:

1. Room size was 10 000 m^3 (353,000 ft^3), a size which might correspond to a representative seafood cold store on the U. S. west coast having 1400 m^2 (15,000 ft^2) floor space and a ceiling height of 7.3 m (24 ft) (S. Ryding of Inland Quick Freeze; S. Thomas of Bellingham Cold Storage).
2. Ambient Temperature was 8° C (46.4° F). Correction for an outside ambient different than 8° C can be estimated by assuming that power varies directly with the overall temperature difference.
3. Product time in storage was 3 months.
4. Room temperature was -25° C (-13° F). Recommendations for surimi fall in the range -20 to -40° C (-4 to -40° F), according to Sonu (1986), S. Thomas (personal communication), and Shaban et al. (1985) .
5. Percent of room utilized was 60%. This coincides with assumptions made by Graham (1984) for cost estimations .
6. Loading density at maximum utilization was 1.6 m^3/t (51. 4 ft^3/ton), which corresponds to 10 kg (22 lbm) blocks stacked on pallets (Graham, 1984).

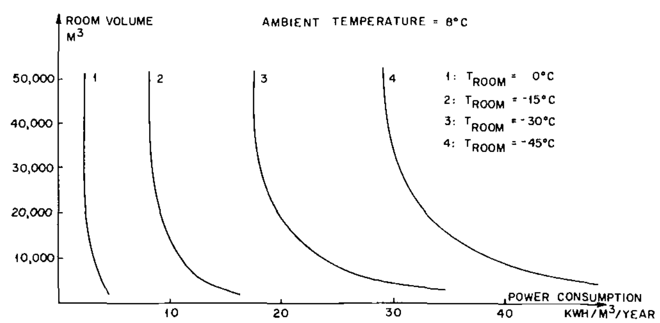

Figure 3–Cold storage power vs. room temperature and size (from Poulsen and Jensen, 1978). Note that

$$1\ m^3 = 35.3\ ft^3,$$
$$1\ kWh/m^3\text{-}yr = 0.028\ kWh/ft^3\text{-}yr,$$
$$T(°C) = [T(°F) - 32] / 1.8.$$

Results of figure 3, combined with these conditions give a specific energy figure of 4.3 kWh/t-mo (3.9 kWh/ton-mo.).

Poulsen (personal communication) stated that the results of figure 3 correspond to performance observed in large, modern, well-designed and managed Danish cold stores. Indeed, the results are an order of magnitude less than specific energy found by Graham (1984) for a small (1000 m^3 or 35,300 ft^3) cold store into which 35 t/day (38.5 ton/day) of relatively warm (-11° C or 12.2° F) product is continually moved. And the value of 4.3 kWh/t-mo (3.9 kWh/ton-mo.) is substantially lower than the values reported in Table 4.

From this it was concluded that:

1. The calculations of Poulsen and Jensen (fig. 3) give results that might be considered an attainable goal, given sound design and management practices;
2. The rate of energy consumed in the cold store dramatically increases when the cold store is used to continuously chill new product;
3. Account might be made for cold store age and some degree of mismanagement by applying a "safety factor" of 5 to the results of Poulsen and Jensen.

Thus, the example calculation (for 60% fill capacity) indicated a specific energy requirement of 4.3 kWh/t-mo. (3.9 kWh/ton-mo.) under ideal conditions, but perhaps a more realistic figure for existing plants would be 21.5 kWh/t-mo (19.5 kWh/ton-mo). This value would be proportional to the storage time, and inversely proportional to the room utilization percentage.

Figure 3 shows that as room size falls below a value of 15 000 m^3 (530,000 ft^3) or so, the increasing surface-to-volume ratio becomes a significant factor. This is even more pronounced as the overall temperature difference increases. Thus, the effect of room size is quite important in tropical climates.

Results under conditions of the given scenario and for a range of cold storage temperatures appear in Table 5. The figures show that a 53% increase in energy consumption results from lowering cold store temperature from -20 to -30° C (-4° to -22° F), a value that coincides with results of Houwing (1984). However, as pointed out by Graham (1984) and FAO (1977), this energy increase is in the "running cost". This cost of cold storage is considered to be a small percentage of the "total cost", when other annual fixed and operating expenses are included. Thus Graham argues that lowering room temperature from -20° C to -30° C (-4° to -22° F) causes a rise in "total cost" closer to 4%. Compared to the 53% predicted rise in cold storage energy cost, this is almost insignificant, and such a temperature decrease could lead to a substantial benefit due to increased product quality.

Cold storage energy efficiency can be improved in many other ways. Savings on the order of 17% have been

TABLE 5. Specific energy vs. storage temperature*

Room temp. (° C)	kWh/m^{3}yr† (fig. 3)	kWh/ t-mo x 5	kWh/ t‡ for 3 mo.
−15	11	12.0	36
−20	15.2	17.0	51
−25	19.3	21.5	65
−30	23.5	26.0	78

* 10,000 m^3 (353,000 ft ^{3}) room size.
8° C (46.4° F) ambient temperature
60% storage utilization
1.6 m^3 / t (51.4 ft^3 / ton) stowage capacity
† 1 kWh/m^{3}yr = .028 KWh/ ft^3 yr
‡ 1 kWh/ t = .9 kWh/ ton

projected for some Oregon refrigeration plants by adjusting the condenser temperatures downward (G. Wheeler, personal communication). And Ashby et al. (1979) pointed out energy savings on the order of 24% if refrigeration equipment is shut down at night, increasing both room temperature and fluctuation. The real tradeoff of this as well as other cold storage temperature management schemes involves their effects upon product quality.

Total

Table 6 presents a summary of results for the representative surimi plant described in this report. Based on this analysis, two major factors influencing results are:

1. Surimi wash water utilization and refrigeration;
2. Cold storage design and measurement.

TABLE 6. Direct energy costs of surimi production (in KWh electrical energy per metric ton * of surimi produced)

	Summer † Alaska	% of total	Summer ‡ Oregon	% of total
In-plant processing	89	33	131	42
Freezing	118	43	118	38
Cold storage	65§	24	65§	20
Total	272		314	

* 1 kWh/ t = .9 kWh/ ton
† Assumes wash water source temperature of 5° C (41° F).
‡ Assumes wash water cource temperature of 16° C (60° F).
§ Cold storage room temperature is −25° C (−13° F).

Acknowledgment. This work is a result of research sponsored by NOAA Office of Sea Grant, Department of Commerce, under Grant No. NA85AA-D-SG-095. The U.S. Government is authorized to produce and distribute reprints for governmental purposes, notwithstanding any copyright notation that may appear hereon. The assistance of the Fishery Industrial Technology Center, University of Alaska in Kodiak is also acknowledged.

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