Fuel Oil and Electricity Consumption in a Kenyan Milk Powder Factory

Michael W. Okoth
Dept. of Food Technology & Nutrition
University of Nairobi
P.O. Box 29053, Nairobi,
KENYA

ABSTRACT

Fuel oil and electrical energy consumption in a milk processing plant was measured daily for a whole year. The plant has a processing capacity of 150 tons of milk per day. The plant primarily produced milk powder and butter. However, no milk powder was produced in the dry season since the milk was pasteurized and taken elsewhere for packaging. Fuel oil consumption averaged 595 MJ per ton milk intake when there was no milk powder production and 2230 MJ per ton milk intake during the milk powder production season. Electrical energy consumption averaged 170 MJ per ton milk intake when there was no milk powder production and 244 MJ per ton milk intake during milk drying season. 82 % of the milk intake was converted to powder during the milk drying season. There is considerable potential for saving energy in the factory. Suggested targets would result in savings of 38% and 41% for fuel oil and electricity, respectively, when there is no milk powder production and 28% and 39%, respectively, during the milk drying season.

1. INTRODUCTION

Energy is required for the various operations in a milk processing plant. Fuel oil is used in boilers to generate steam. The steam is used for cleaning and disinfection as well as for process heating. It may also be used for vapor compression and for steam jet vacuum production. Electrical energy is required to power electric motors and to provide lighting. It may also be used for heating purposes.

There is need to save energy in Kenyan milk processing factories [1]. Considering all the 12 factories operated by Kenya Co-operative Creameries Ltd (KCC), the cost of electrical energy averaged 2.3% of the total operating cost, excluding the cost of raw milk and cream, from 1981 to 1988. In the same period, fuel oil accounted for an average of 5.2% of the total operating cost (the highest figure was 7.0% in 1983). The factories produce pasteurized/UHT liquid milk, powdered milk and butter.

The consumption of fuel oil and electrical energy in the milk factory studied (from 1981 to 1988) was much higher than for the above average figures. The share of electrical energy in the total operating cost of this factory, excluding the cost of raw milk and cream, varied from 8.5% in 1981 to 1.1% in 1985 and averaged 4.7%; while that of fuel oil varied from 24.0% in 1983 to 5.3% in 1985 and averaged 16.2%. It is thus evident that reducing energy consumption would have a marked impact on the profitability of milk processing factories, especially milk powder plants, and especially at periods of high energy prices in the volatile energy market.

Other benefits of energy conservation in milk processing plants are: (1) the national energy import bill is reduced thus alleviating the balance-of-payments problem; (2)the pressure on the electricity supply infrastructure is reduced; and (3) negative environmental impacts associated with energy production are reduced.

Fuel oil and electrical energy consumption in a milk processing factory was measured daily for a whole year. This factory primarily produced milk powder and butter. The processing capacity was 150 tons of input milk per day. However, no milk powder was produced in the dry season since the milk was pasteurized and taken elsewhere for packaging.

2. PROCESSING OPERATIONS AND MEASUREMENT METHODS

2.1 Processing Operations

The processing operations in the factory are shown in Fig. 1.

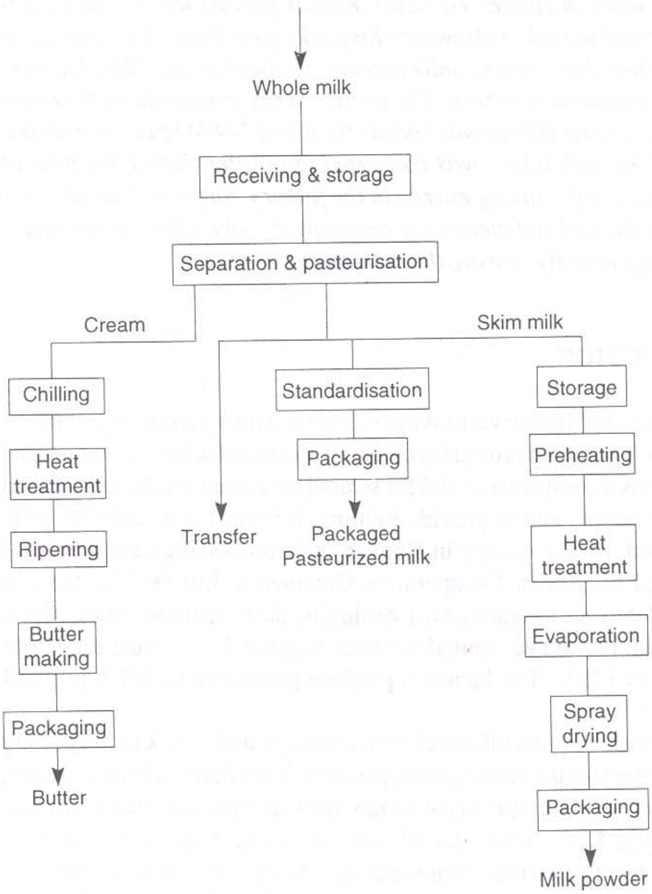

Fig. 1. Processing operations.

In the milk reception section, electrical energy is used to run motors and to provide the chilled water used to cool the milk in a plate heat exchanger. The milk is delivered in 50 liter cans and steam is used to heat water in the can washing machines.

The milk pasteurization section uses electrical energy to run motors and to chill the water used in the milk chilling section of the plate heat exchanger. Steam is used as the heating medium in both pasteurization and cleaning-in-place (CIP). The extent of heat regeneration in the plate heat exchanger is 90%.

In the butter section, electrical energy is used to run motors and to provide chilled water for cooling the incoming warm cream, the heat treated cream in the plate heat exchanger and the butter in the continuous butter making machine. Steam is used for heat treatment of butter in the plate heat exchanger whose extent of heat regeneration is 70% as well as for heating cleaning water.

In the milk powder production section, electrical energy is used to drive various motors both in the evaporation and drying units. In the evaporation system steam is used for heat treatment of milk feed and for concentration of the milk. Steam is also required for cleaning the evaporation system. In drying, steam is used to heat the air supplied to the spray drier. Steam is also used when the spray drier is being cleaned.

A three-stage falling film evaporator is used. Steam at 10 bar sucks some of the vapor leaving the first effect evaporator, compresses it in a thermocompressor and the steam-vapor mixture so obtained is used as the heating medium in the first effect evaporator. The remaining vapor from the first effect evaporator serves as the heating medium in the second effect evaporator. Similarly, the vapor from the second effect is the heating medium in the third effect evaporator. The vapor from the third effect evaporator is condensed by direct contact with cold water. The condensate from the first and second effects flows down the drain. The milk feed is preheated by passage through coils in the vapor separators located after each evaporation stage. Further heating to about 75 °C is done by means of steam.

For general cleaning of the factory using hose pipes, steam and cold water are mixed as desired and there is no provision for automatic shut-off of the hose pipes when the cleaning exercise is completed.

2.2 Measurement Operations

2.2.1 Fuel oil consumption

Daily dipstick measurements in the oil tanks provided daily fuel oil consumption.

2.2.2 Electricity usage

The total electrical energy consumption is metered by the utility firm, Kenya Power and Lighting Co. Ltd. Their meters were used for the present study. They provided the total electrical consumption in kWh per day.

2.2.3 Milk intake

The milk in each 50 l can was weighed in a computerized weighing system and the total daily intake computed.

2.2.4 Milk powder production

The milk powder was packaged and recorded in 50 kg units.

3. RESULTS AND DISCUSSION

3.1 Milk Intake and Production

Fig. 2 shows the monthly milk intake. It varied from 2635 tons in March to 3760 tons in October. The monthly production of skim-milk powder and butter is shown in Fig. 3. The production of these products showed more or less the same trend. The main production season for both products was between May and December. There was no milk powder production in March.

3.2 Fuel Oil Consumption

Fuel energy consumption per ton of milk intake (specific fuel energy consumption) for each month is shown in Fig. 4. The lowest figure of 573 MJ per ton milk intake occured in March when there was no milk powder production while the highest figure of 2234 MJ per ton milk intake was experienced in December. The average specific fuel energy consumption in May, June, July, September and December (when milk powder production was in full stream) was 2230 MJ per ton milk intake. During this period 82% of the milk intake was converted to powder.The average specific fuel energy consumption in all the days when there was no milk powder production was 595 MJ per ton milk intake. 7 % of the total number of days considered had specific fuel energy consumption figures varying between 300 MJ per ton and 400 MJ per ton milk intake.

Fig. 5 shows the relationship between the daily specific fuel energy consumption and the milk intake when there was no milk powder production. The apparent scattering of points leads to the conclusion that there is no marked relationship. Multiple linear regression does not show any meaningful relationship between the daily fuel energy consumption and the daily liquid milk and butter production.

It can be concluded that during the season of milk powder production, the daily milk intake alone is not a sufficient indicator of the fuel oil consumption. In view of the energy intensity of the evaporation and drying processes, a relationship between the amount of milk powder produced and the fuel consumption can be anticipated. Fig. 6 shows the relationship between the daily specific fuel energy consumption and the milk powder production in kilograms per ton milk intake. Although the points are somewhat scattered, there appears to be a direct relationship between the two variables. A linear regression reveals the following equation:

$$\text{Daily specific fuel energy} = 1674 + 6.05 \times (\text{kg milk powder/ton milk}) \qquad \text{(MJ/t milk intake)} \qquad (1)$$

The application of Eq. 1 to all the points indicated in Fig. 6 results in an average error (deviation from the actual daily specific fuel energy consumption) of 18.6%.

Eq. 2 shows the relationship between the daily fuel energy consumption and the daily quantities of pasteurized milk and milk powder produced obtained by multiple linear regression:

$$\text{Daily fuel energy} = 28870 + 1.0 \times PM + 11.8 \times MP \qquad \text{(MJ)} \qquad (2)$$

where PM is the daily amount in kg of liquid milk pasteurized and MP is daily production of milk powder in kg.

The correlation coefficient for Eq. 2 is 0.80.

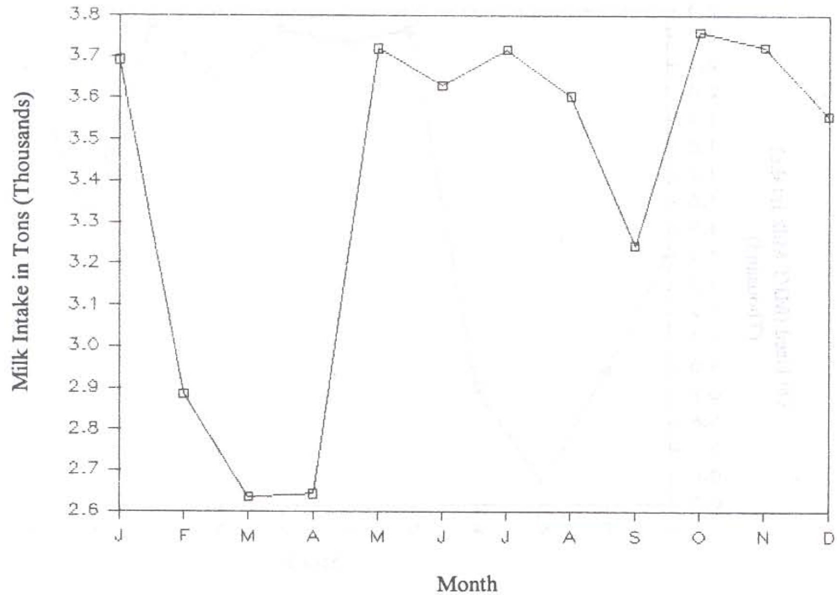

Fig. 2. Monthly milk intake.

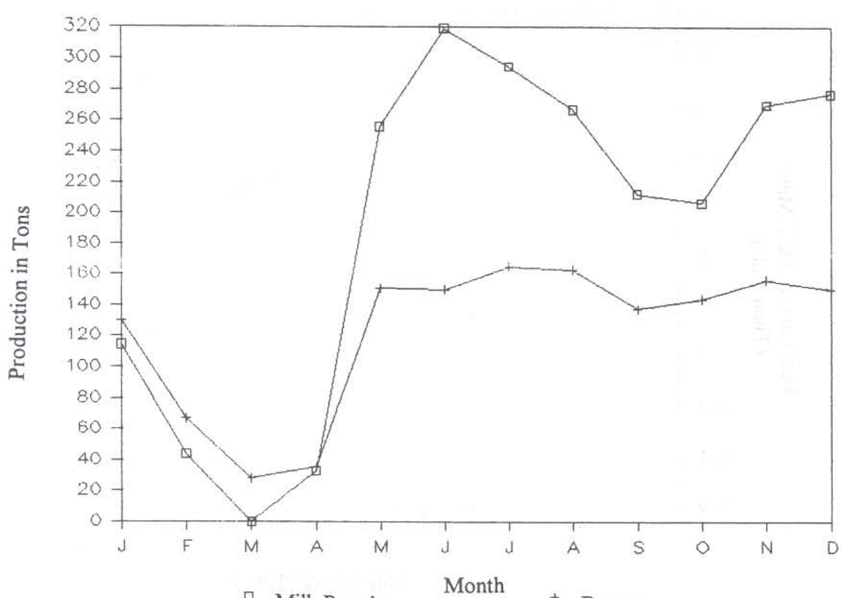

Fig. 3. Monthly production of milk powder and butter.

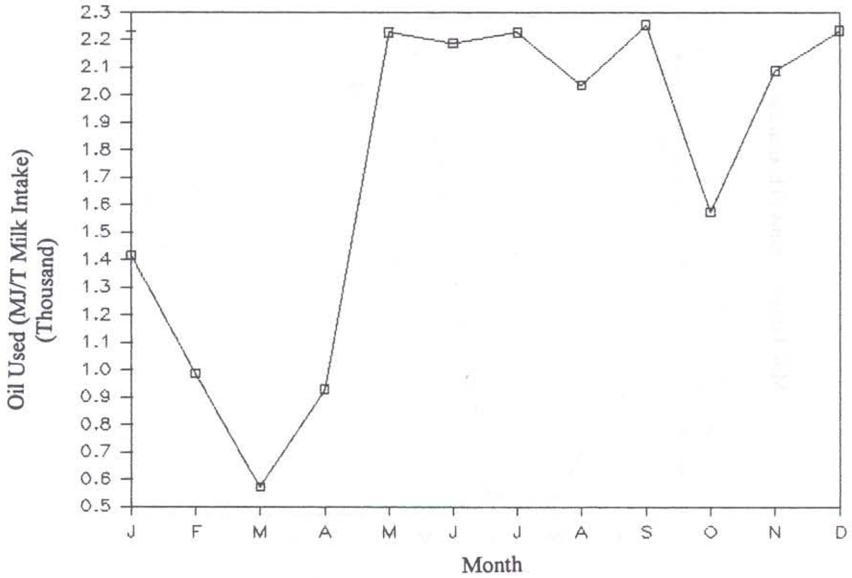

Fig. 4. Monthly specific fuel oil consumption.

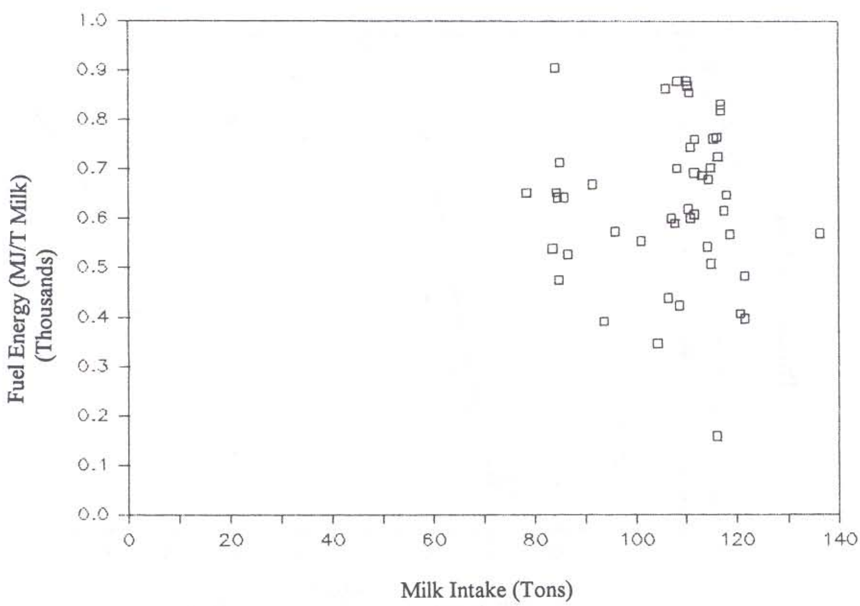

Fig. 5. Relationship between daily specific fuel energy consumption and milk intake when milk powder was not produced.

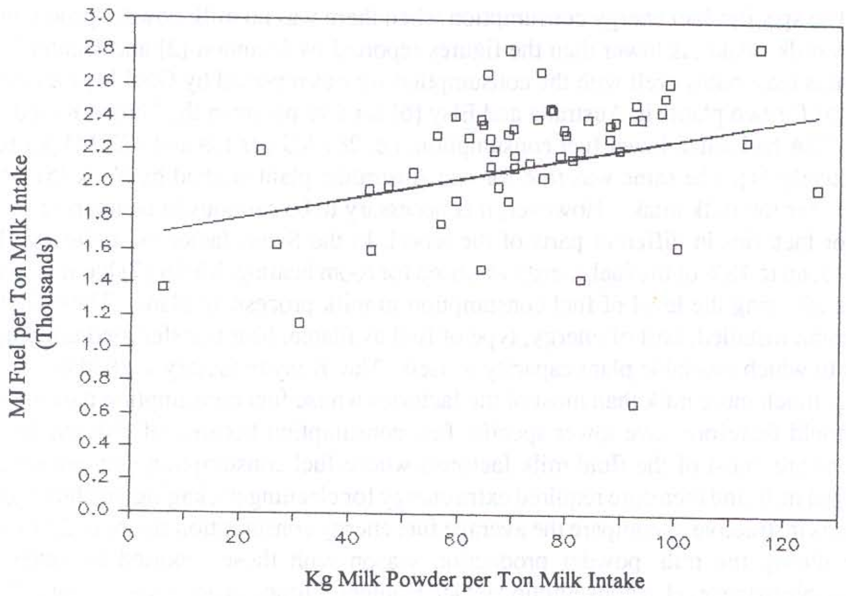

Fig. 6. Relationship between daily specific fuel energy usage and milk powder produced per ton milk intake.

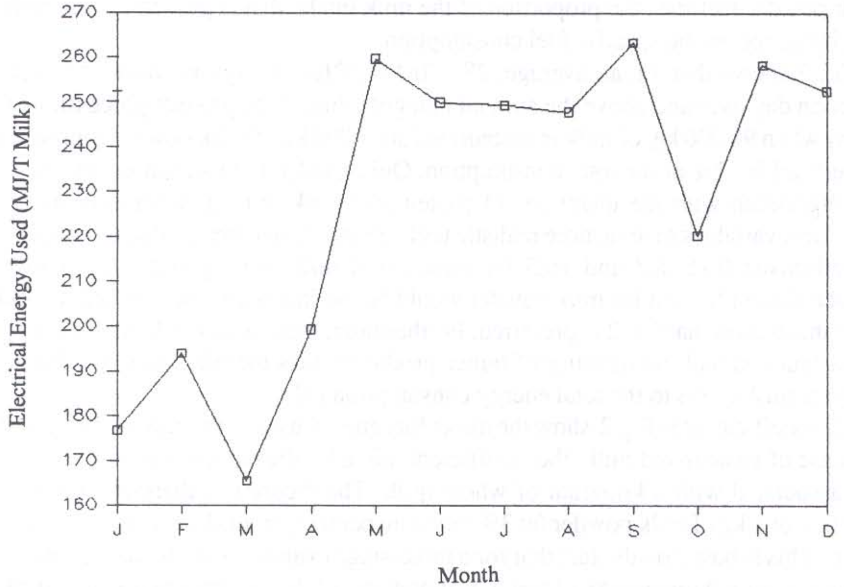

Fig. 7. Monthly specific electrical energy consumption.

The specific fuel energy consumption when there was no milk powder production, i.e. 595 MJ per ton milk intake, is lower than the figures reported by Shannon [2] and Hunter [3]. It, however, compares reasonably well with the consumption figures reported by Goel [4] for one plant in India, Tuck [5] for two plants in Australia and Elsy [6] for five plants in the United Kingdom. Two plants in the USA had much lower fuel consumption, i.e. 281 MJ per ton and 432 MJ per ton milk intake, respectively [4]. The same was true for one Australian plant studied by Tuck [5] which consumed 340 MJ per ton milk intake. However, it is necessary to be cautious in comparing fuel consumption data for factories in different parts of the world. In the Swiss factories studied by Hunter [3], for instance, up to 18% of the fuel energy was used for room heating. Miller [7] has discussed some of the factors affecting the level of fuel consumption in milk processing plants. These include age of the equipment installed, cost of energy, type of fuel available, heat transfer medium employed and the extent to which available plant capacity is used. The Kenyan factory studied by the present author handles much more milk than most of the factories whose fuel consumption data are reported above and should therefore have lower specific fuel consumption because of efficiencies of large scale. Furthermore, most of the fluid milk factories whose fuel consumption data are reported produced packaged milk and therefore required extra energy for cleaning packaging machines and milk bottles.

It is instructive to compare the average fuel energy consumption figure of 2230 MJ per ton milk intake during the milk powder production season with those reported by other workers. It is comparable to the level of consumption which Hunter [3] found in one Swiss factory. Two other Swiss milk powder factories studied by Hunter [3] had considerably lower fuel consumption than the Kenyan factory, i.e. 1826 MJ per ton and 1269 MJ per ton milk intake, respectively. Similarly, the figure of 1630 MJ per ton milk intake reported by Shannon [2] for New Zealand milk powder factories is 27% lower than the Kenyan factory's consumption. Goel [4] also reported a lower specific fuel consumption, i.e. 1932 MJ per ton milk intake, in one USA milk powder plant. One has to bear in mind the remarks made about regarding the difficulty of comparing data from different plants. Furthermore, in the case of milk powder factories the proportion of the milk intake that is processed into milk powder has a strong influence on the specific fuel consumption.

Eq. 2 shows that, on an average, 28 870 MJ of fuel energy is consumed each milk powder production day over and above the amount that goes directly to product processing. This means that on a day when 90 000 kg of milk is pasteurized and 4000 kg of milk powder is produced, fuel energy use overhead is 17% of the total consumption. Quite evidently this is an underestimate. A multiple linear regression with the quantities of pasteurized milk, milk powder and butter production as independent variables gives a more realistic fuel energy use overhead value of 78 080 MJ per day with the coefficients 0.15, 8.3 and 16.5 for pasteurized milk, milk powder and butter, respectively. However, the coefficient for milk powder would be too low while that for butter would be too high. It is for this reason that Eq. 2 is preferred. Furthermore, there is a correlation between the amount of milk pasteurized and the quantity of butter produced. It is therefore not possible to identify their separate contributions to the total energy consumption [9].

The coefficients in Eq. 2 show the direct fuel energy used to process a kilogram of each product. In the case of pasteurized milk, the coefficient includes the energy used for processing cream and butter associated with a kilogram of whole milk. The theoretical thermal energy requirement for production of 1 kg of milk powder (at 3% moisture content) from skim milk at 5 °C is 10.4 MJ per kg powder. This is based on the fact that for a three-stage evaporator with thermocompression, 0.25 kg of steam is required for each kg of water evaporated [10]. It compares reasonably well with the value of 11.8 MJ per kg of milk powder indicated by Eq. 2. The theoretical thermal energy required to pasteurize 1 kg of whole milk and to heat treat the cream separated from it is 0.0385 MJ. This is much lower than the value of 1.0 MJ per kg pasteurized milk shown in Eq. 2. Apart from error in the determination of the coefficient, this could be due to inefficiency in steam utilization.

3.3 Electrical Energy Consumption

Fig. 7 shows the monthly specific electrical energy consumption. The lowest figure of 166 MJ per ton milk intake occured in March when there was no milk powder production while the highest figure of 263 MJ/t was found in September. The weekly specific electrical energy consumption when there was no milk powder production varied from 140 MJ per ton to 188 MJ per ton milk intake and averaged 170 MJ/t. There was a wide variation in the daily specific electrical energy consumption with the lowest values varying between 80 MJ/t and 90 MJ/t milk intake and the highest values lying between 190 MJ/t and 200 MJ/t.

The relationship between the daily specific electrical energy consumption and the milk intake when there was no milk powder production is depicted in Fig. 8. It indicates a linear decrease of the daily specific electrical energy consumption with increasing milk intake. Eq. 3 fits the data with an average error of 7.1%:

$$\textit{Daily specific electrical energy} = 307.8 - 1.5 \times (\textit{Milk intake in tons}) \quad \text{(MJ/t milk intake)} \tag{3}$$

Multiple linear regression to relate the daily specific electrical energy consumption and the daily production of pasteurized milk and butter yielded a correlation coefficient of only 0.51 and could therefore not result in meaningful coefficients.

The average specific electrical energy consumption over a period of 33 weeks when milk powder was produced amounted to 244 MJ per ton milk intake.

Fig. 9 shows the relationship between the weekly specific electrical energy consumption and the milk powder production (kg powder per ton milk intake). One can detect a general increase of the dependent variable with increase of the independent variable. The following linear relationship fits the data with an average error of 9.3%:

$$\textit{Weekly specific electrical energy} = 213 + 0.49 \times (\textit{kg powder/t milk intake}) \quad \text{(MJ/t milk intake)} \tag{4}$$

Multiple linear regression yielded the following equation with a correlation coefficient of 0.76:

$$\textit{Daily electrical energy consumption (MJ)} = 2793 + 0.16 \times PM + 0.90 \times MP \tag{5}$$

where *PM* is the daily quantity of pasteurized milk in kg and *MP* is the milk powder produced in kg per day.

The average specific electrical energy consumption of 170 MJ per ton milk intake when there was no milk powder production is quite high when compared with the figures obtained by Elsy [6] for UK fluid milk plants which averaged 97 MJ per ton milk intake. Two of the Australian fluid milk plants studied by Tuck [5] also had lower electrical energy consumption figures, i.e. 148 MJ/t and 155 MJ/t milk intake, respectively.

The average specific electrical energy consumption figure of 244 MJ per ton milk intake during

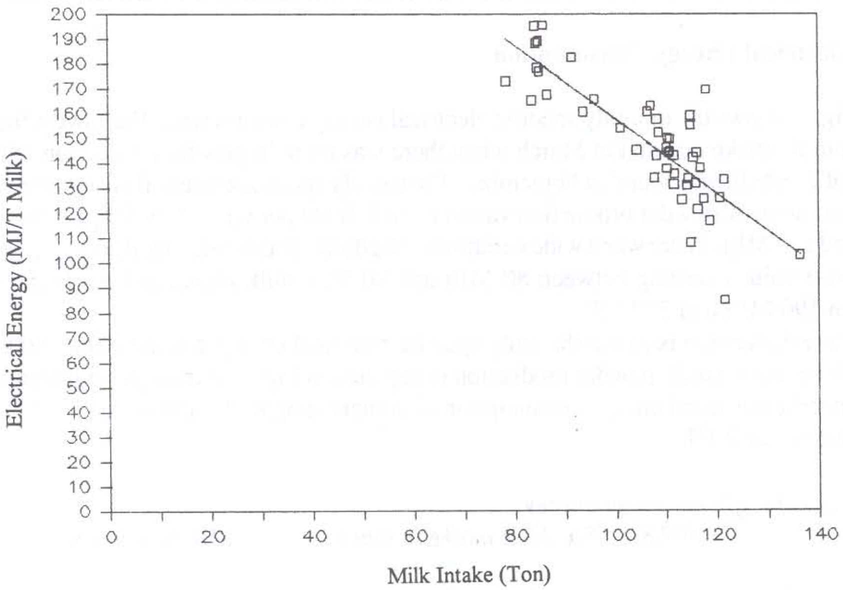

Fig. 8. Relationship between the daily specific electricity usage and milk intake when there was no milk drying.

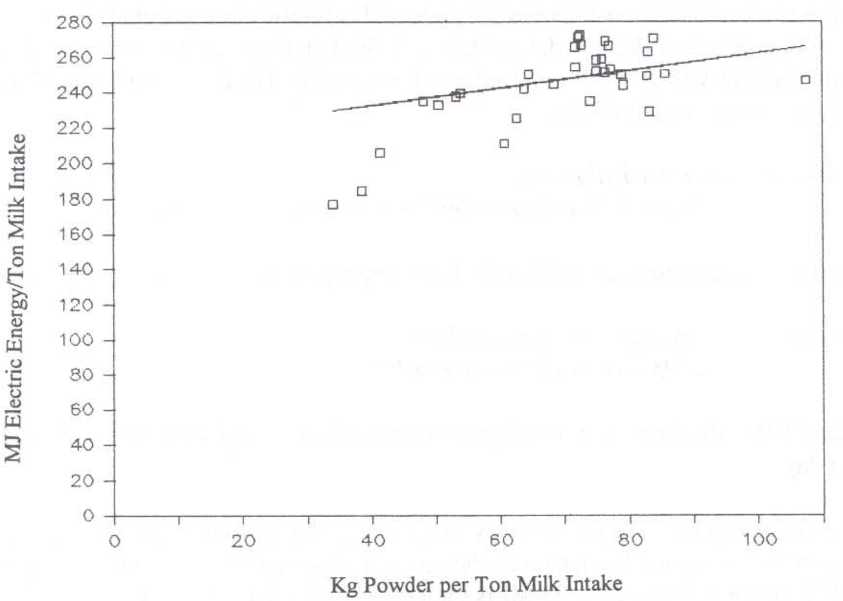

Fig. 9. Relationship between the specific electricity consumption and powder output per ton milk intake.

milk powder production is much higher than the figures reported by Emch [8] for an English plant (138 MJ/t milk intake), Miller [7] for New Zealand milk powder plants (138 MJ/t milk intake) and Goel [4] for a USA plant (103 MJ/t milk intake).

Eq. 5 shows that the baseload for electrical energy is 2793 MJ per day when milk powder is being produced. Its coefficients show that 0.16 MJ is required for each kg of whole milk pasteurized (including cream and butter processing) while 0.90 MJ is required to produce 1 kg of milk powder starting from skim milk. The total thermal energy extracted by chilled water from 1 kg of whole milk and its associated cream during processing is 119.5 kJ per kg milk. This energy has to be transferred to the evaporator of the refrigeration system. Loeffel [11] found that the ratio of refrigeration duty to the total electric power consumption by refrigeration systems in dairy factories varied from 2.2 to 2.4. He considered the electric power consumed by the chilled water stirrer, pumps and compressors. It follows therefore that production of chilled water for cooling of milk and cream theoretically requires electrical energy amounting to 0.054 kJ per kg of whole milk received. This is 33.8% of the coefficient in Eq. 5. The rest of the electrical energy input is accounted for by the other power consuming equipment and inefficiency in the chilled water generation system.

4. CONCLUSIONS

4.1 Fuel Consumptiom

Fuel oil consumption averaged 595 MJ per ton milk intake when there was no milk powder production. Consumption figures as low as 350 MJ/t were obtained in about 7% of the days considered. The target of 370 MJ per ton milk intake set by Tuck [5] for the New South Wales milk processing industry is therefore realistic for the Kenyan factory. The potential fuel energy saving is thus 38% of the prevailing consumption.

Fuel oil consumption during the period of milk powder production was 2230 MJ per ton milk intake. The lower figure of 1600 MJ per ton milk intake obtained on some days when all the milk was dried is equal to the average figure obtained by Shannon [2] for the New Zealand milk powder factories. This is therefore a realistic target for the Kenyan factory during the milk powder production season. The potential fuel saving is thus 28% of the prevailing consumption.

4.2 Electrical Energy Consumption

When there was no milk powder production, the average electrical energy consumption was 170 MJ per ton milk intake. The figure was, however, found to decrease with increasing milk intake. Consumption figures lying between 80 MJ per ton and 90 MJ per ton milk intake were also found. The target consumption should therefore be 100 MJ per ton milk intake, i.e. the goal should be to reduce the consumption by 41%.

When there was milk powder production, electrical energy consumption averaged 244 MJ per ton milk intake. The reported data for similar factories indicate that 150 MJ per ton milk intake is a realistic target figure. The potential saving during the drying season is thus 39%.

4.3 Energy Saving Measures

The following energy saving measures are recommended:

(a) Saving fuel energy
- Increase of boiler efficiency
- Minimization of steam distribution losses
- Re-use of all steam/vapor condensate
- Minimization of the quantity and temperature of the cleaning water and fitting automatic shut-off valves on hose pipes
- Improving process control

(b) Saving electrical energy
- Minimizing losses in the refrigeration system
- Not running machines when they are not required
- Maintaining all machines in good working order
- Switching off lights when they are not required
- Installing energy efficient electric motors

5. ACKNOWLEDGEMENTS

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