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Effective energy management in a commercial multi-product dairy plant through a graphical user interface

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Abstract
Energy management has become a vital activity in large capacity multi product dairy plants in India where a substantial amount of energy is used daily for processing of milk and milk products. Therefore, a need was felt to develop an energy management software (EMS) using Graphical User Interface (GUI) for energy saving. A multi product co-operative dairy plant was selected for this problem. During preliminary observations it was found that the average handling capacity of the plant was 1,50,000 liters per day and it produced several products like table butter, peda, paneer, dahi, ice-cream, lassi and mattha along with fluid milk. The per day consumption of water, steam, refrigeration and electricity in the plant were measured per 100 litres of milk. The water to milk ratio in the plant was more than the standard amount (1.5-2.5 L) hence, action should be taken to minimize the water consumption, which could also reduce the electricity bill. The monitoring and control of each and every activity on everyday basis makes the system complex, which requires huge effort and expenditure. Therefore, high energy consuming activities were termed as “Critical control points”. Using Microsoft Visual Basic 6.0, GUI an “Energy Management Software”, was developed to create an ‘energy consumption data base’ for each process or equipment for record keeping and their analysis. The developed GUI served the purpose of periodic monitoring of energy consumed in the plant and categorized each equipment and processes into different classes as per ABC analysis. This analysis enables the plant personnel of the concerned dairy plant to take appropriate actions for effective energy management. After implementing the GUI, per day consumption of water, steam, refrigeration and electricity in the plant were found to be 238.2 liters, 12.95 kg, 11.94 kJ and 5.98 kWh respectively per 100 L of milk.

Keywords: GUI, EMS, ABC analysis, Critical Control Points.

1. Introduction

The scarcity of energy resources warrants efficient and effective utilization of energy at all levels by all the consumers worldwide. Energy conservation activities are continuously raising in every sector owing to ever increasing energy prices and the Kyoto Protocol has attached an increased importance to energy efficiency (Damien *et al*., 2007) [2]. Dairy industry uses considerable amount of energy for processing of milk, manufacture and storage of various products (Damodaran *et al*., 2004) [3]. On an average, energy cost constitutes about 30-50% of overall manufacturing cost of different products (Verma, 2001 and Pandya, 1998) [13-14, 8]. The cost of energy sources is directly proportional to processing and manufacturing cost of dairy products. Co-operative organizations aim to provide highest possible price for the raw milk irrespective of the realization from the sale of products. Hence, only the plant efficiency will become the success key to both productivity and success of the management of a dairy plant (Solanky, 1998) [11]. Energy in dairy plants directly refers to the utilities generation i.e. steam, refrigeration, electricity and water. Electricity and fuels are used for the generation of other utilities, pumping of different liquids and illumination. Water is used for cooling, heating, cleaning, dilution of solutions, steam generation, ice/chilled water production and for direct processing. In dairy plants ice-bank system of refrigeration is used generally for chilling and processing of milk while direct expansion air chillers are employed for cold storage. Steam is used for heating, cleaning and sterilization. It is estimated that one-third of the total energy used by the dairy plant is actually utilized in the processing operations, while refrigeration plant consumes about 50-60 % of total electrical consumption (Bhadania, 1998) [1]. To run the plant economically and efficiently, availability of accurate consumption data of these utilities is mandatory. The goal of an energy management program like Energy Management Software

(EMS) is to monitor, record, analyze, critically examine, alter and control energy flows so that energy is always available and utilized with maximum efficiency (O'Callaghan, 1993, Rahman, 1986) [7, 10]. Energy audit is a way to evaluate the total energy consumption in any plant, but for the implementation of the outcomes of an audit requires extra budgets and maintaining the whole system up to the mark is a great time consuming effort. Hence, a professional approach using GUI towards maintaining the energy consumption and plant efficiency on day-to-day basis is required.

2. Materials and Methods

2.1 Plant Details

A multi-product dairy plant was selected for the present study to develop a GUI based energy management software. The plant is mainly engaged in the processing of fluid milk with different fat content (6.0%, 4.5%, 3.5%, 3.0% and 1.5%). It also manufactures Ghee, Peda, Table Butter, Paneer, Ice-cream, Dahi, Misti dahi, Lassi and Mattha. The present handling capacity of the plant is 1, 50,000 L/ day with the average reception of milk ranges from 38,000 to 40,000 L per day from cans and rest quantity of milk is received through road milk tankers. The plant has facility for cold storage of 60,000 L market milk, 2000 L of dahi and lassi. Deep freeze with -15 ^{O}C to -25 ^{O}C working temperature is also available for hardening and storage of 4,000 L of ice-cream. The steam demand is met by a horizontal oil fired boiler. The steam supply rate from the boiler is 6,000 kg/ h at the maximum working pressure 17.5 kgf/cm^2.

2.2 Methodology used for plant data collection

Temperature measurement: Temperatures at various points were measured by using mercury thermometers, temperature recorders and dial thermometers fitted with equipment. At various points of batch processes and product manufacturing sections, temperatures were measured by using mercury thermometers. Pasteurizer milk temperature after heating section was measured by temperature recorders connected to the holding section of the HTST pasteurizer. The temperature of milk, cream, hot and cold water were measured respectively at inlet and outlet points by mercury thermometers.

Flow measurement: Any of the following three methods were used to determine the flow rates of milk, hot water and cold water viz., a) Bucket method, b) Tank level method and, c) Heat balance method. In Bucket method, a known quantity of the liquid was collected in a container for a specific time period. In each case three replications were made and the average was taken as the final measurement. This method was used to measure the flow rate of water or condensate in processing and washing section. In tank level method, the drop or rise in the level of tank or silo depending upon the case was noted in a known time. The mass flow rate was calculated by measuring the tank or silo diameter or cross section and density of liquid. It is used to measure the flow rate of milk entering through the chiller and pasteurizer. The mass flow rate of water as well as oil used in the boiler in a known time was also measured by this method. Heat balance method was applied when there was no adequate facility available for the flow measurement during running plant. This method was used to measure the flow rate of hot and cold water entering and leaving the pasteurizer. The mass flow rate was calculated by the following heat balance equation.

Heat loss = Heat gain (Taking 10% loss to the atmosphere)

Steam measurement: Steam pressure at various heating points was measured by steam gauge fitted at steam inlets at various equipment and units. The condensate weighing and enthalpy balance methods recommended by Prabhakar *et al.* (2015) [9] were employed to measure the steam flow rate in various sections (Lyle, 1947) [6].

2.3 Methods for calculation

The following procedure and methods were employed in calculation of utilities consumption are:

Water: In milk or cream processing section, water was mainly required for cleaning of HTST pasteurizer, storage tank and washing of floor. Make up for hot water heater of HTST pasteurizer was negligible in quantity in respect of the cleaning of pasteurizer. Water consumed during cleaning of pasteurizer in each cleaning was determined by multiplying the flow rate and draining time. In ghee, peda, paneer, ice-cream and cultured products section, the water was used for washing equipment and floor. The water used was calculated by multiplying the flow rate of water and the time required for cleaning.

Steam: Steam consumption in can washer where the caustic solution was heated by direct steam injection to maintain the desired temperature, was estimated by enthalpy balance method. In can sanitization the steam used was estimated by condensate weighing method. The steam consumption in the pasteurizer of the plant where the milk was heated by hot water using steam by direct mixing was calculated by enthalpy balance method. The steam gauge fitted at steam inlets at various equipments will provide steam pressure at various heating points. Assuming steam used throughout the plant is saturated. Hence, the temperature, enthalpy and latent heat of the saturated steam at its absolute pressure P_S (Pa) will be calculated by the following regression equations 1 and 2 (Das, 2005) [4] developed from the data given in the steam table.

$$T_S = \frac{3723.67}{(23.0603 - \ln(Ps * 98100))} - 222.857 \quad \ldots (1)$$

$$H_S = 2501+1.88*T_S; \; L_S = 2501+1.88*T_S-4.184*T_S \quad \ldots (2)$$

Where, $_S$ = Temperature of saturated steam at P_S, ^{0}C; $_S$ = Enthalpy of saturated steam at P_S, kJ/kg; L_S = Latent heat of saturated steam at P_S, kJ/kg; P_S = Saturation steam pressure, kgf/cm^2.

Refrigeration: The raw milk as well as pasteurized milk was chilled by using chilled water and the refrigeration consumption during this process was calculated by equation 3 ((Gedam, 1997) [5].

$$Q = \frac{M_C \, C_P(T_2 - T_1)}{12708} f \quad \ldots (3)$$

Where, Q = Refrigeration load, kJ; M_C= Chilled water mass flow rate, kg/h ; Cp= Specific heat of chilled water, kJ/kg K ; T_1 = initial chilled water temperature, ^{0}C; T_2 = final chilled water temperature, ^{0}C; f = a factor, which takes into account of heat lost in chilled water pipe while conveying it from chilled water tank to equipment. The direct expansion air chillers are employed in dairy plant for cold storage and the actual refrigeration load was calculated by the following method. The mass refrigerant flow rate was calculated by equation 4 (Gedam, 1997) [5].

$$M = \frac{(\Pi/4)(L * N)D^2 * n * 60}{Vg} \quad \ldots (4)$$

Where, M = Refrigerant mass flow rate, kg/h; D = Compressor bore diameter, m; L = Compressor stroke length, m; N = Speed of the compressor, rpm; n = No. of cylinders and; Vg = Specific volume of refrigerant at suction pressure, m^3/kg. The net refrigerant effect was calculated by equation 5 (Gedam, 1997) [5].

$$Q = H_g - H_f \quad \ldots (5)$$

Where, Q = net refrigerant effect, kJ/kg; H_g = enthalpy at the suction to the compressor, kJ/kg; H_f = enthalpy at the discharge of expansion valve, kJ/kg; Total refrigerant effect, kJ/h = M * Q; Refrigeration load, kJ/day = Q*hours of operation per day.

Electricity: The measurement of actual electrical consumption is not feasible in a plant. However the electrical consumption will be calculated from the HP rating and the time of operation of the drive motors of the pumps, conveyors, agitators, blowers, fans etc. The electrical consumption in lighting and other purpose was calculated by noting the number of tube-lights, bulbs, number of aseptic filling or packaging machine, electronic weighing machine, electronic sealing machine, electrical freezer and their Wattage with the operating hours. Current transformer or Tongue tester was also used for accurate consumption of electricity in different sections.

$$1 \text{ kWh or } 1 \text{ unit} = \frac{\text{Watt rating of the device} * \text{hours used}}{1000} \quad \ldots (6)$$

2.4 Methodology for an Effective Energy Management

A multi-product dairy industry produces several types of products and each product has a unique process of manufacturing, also the numbers of equipment and processes are numerous in a multi-product dairy plant; hence control of all the processes or equipments towards an effective energy management would require huge time and effort (managerial and financial). To achieve the objectives of energy optimization and management of a multi-product dairy plant with minimum time and expenditure, a unique action plan was introduced and adopted for the selected plant as shown in Table 1.

Table 1: Steps used for effective energy management

Step	Action	Objective
Step1.	Prepare the process flow chart for each product with the objective of type of energy involved.	To simplify the complex problem for effective energy monitoring and control.
Step 2.	Energy inputs, consumption levels at each system & sub-system are computed using GUI based software.	To get the daily consumption of energy in each process with the histograms for their comparison.
Step 3.	ABC / Pareto analysis of energy consumption in system & sub-system.	To assist the decision maker to set priorities for the effective decision.
Step 4.	Micro analysis of classes A and B sub-systems equipment-wise and energy type-wise.	To identify the actual problem area and declare CCPs for regular monitoring & control.
Step 5.	Comparison with the standard norms related to energy consumption in each equipments and processes.	To compare the system or process with easily available findings on the similar systems or processes.
Step 6.	Taking appropriate decision for effective energy conservation for the plant.	Solely depends on the management of the associated dairy plant

2.4 Software used for Energy Computation and their Analysis

Since the computers are capable of very rapid calculation and are able to generate data much faster than a person is able to assimilate it. Hence, to develop energy input data base of energy consumption in different process or equipments for record keeping as well as their analysis, GUI based software will be requisite. A programme was developed with the aid of Microsoft Visual Basic 6.0 and was named as "Energy Management Software", (EMS) for the set objectives. EMS, not only serve the purpose of periodical monitoring of the energy consumption in the plant but also categorize the equipments, processes and sub-processes into different class by using ABC analysis embedded in the EMS, depending on the energy consumption during that span. The utilities consumption in each process or section was tabulated in descending order of percentage cumulative and was plotted into the histograms. The graphics presentation has the advantage of making data points, trends and relationships much more apparent than purely tabular data ever can. These analyses will help the plant personnel of the concerned dairy plant to take appropriate actions for effective energy management.

3. Results and Discussion

According to the methodology prescribed, the energy consumed per activities was calculated by EMS developed during the study and is presented here under following sub heading:

3.1 Developed EMS and its practical execution

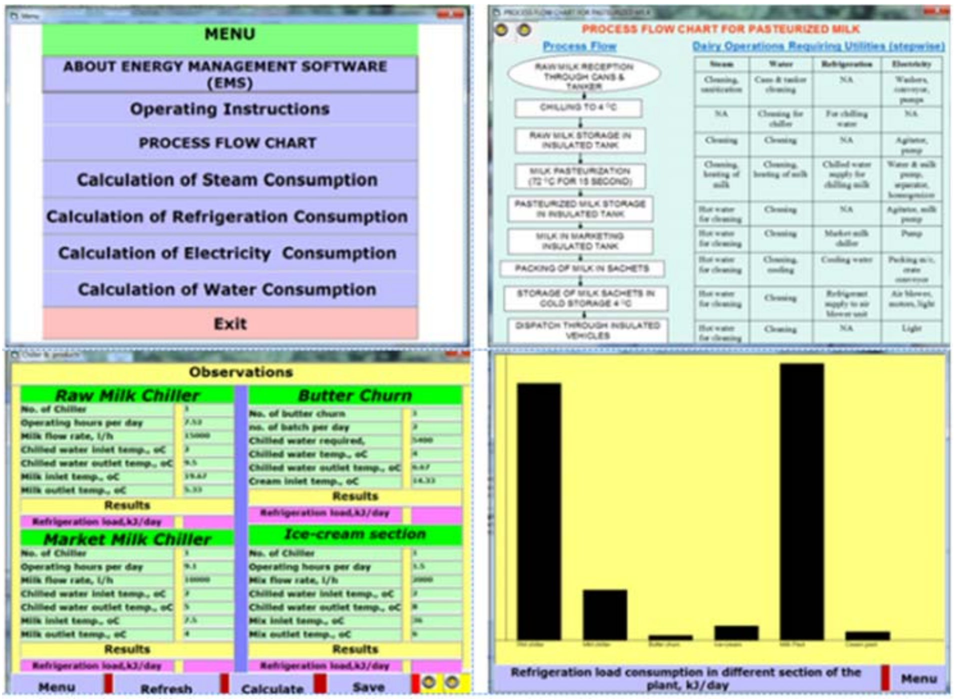

Fig 1: Print screen of GUI based EMS

Table 2: Unit operation wise water and steam requirement in various product sections of dairy plant

Unit operations	Water Requirement	Steam Requirement
Can washing	4.29 L/can	0.24 kg/can
Crate washing	1.33 L/crate	0.196 kg/crate
Dump tank and weighing bowl washing	382.13 L/ cleaning	-
Pasteurization of milk	-	4.09 kg/100 L of milk
Pasteurization of cream	-	5.45 kg/100kg of cream
Chemical cleaning of pasteurizer	9920 L/ cleaning	385.625 kg/ cleaning
Chemical cleaning of cream pasteurizer	5546.4 L/ cleaning	272.35 kg/ cleaning
Cream separator cleaning	611.38 L/ cleaning	
Dahi processing	1.86 L per kg of dahi	0.81 kg/kg of dahi
Peda processing	8.6 L per kg of peda	4.46 kg/kg of peda
Paneer processing	0.57 kg/kg of milk processed	1.77 L per litre of milk
Ghee processing	2.8 L per kg of ghee	0.96 kg/kg of ghee
Ice-cream processing	0.518 L per litre of ice-cream mix	0.46 kg per litre of ice-cream mix
Lassi or mattha processing	0.26 L per litre of product	0.45 kg per litre of product

Table 3: Unit operation wise refrigeration requirements in various product sections of dairy plant

Unit operations	Water Requirement
Raw milk Chilling	0.54 kJ/100 L of milk
Processed milk chilling	0.386 kJ /100 L of milk
Cream chilling	0.255 kJ /100 L of cream
Paneer processing	0.31 kJ /100 L of milk
Ghee processing	2.8 L per kg of ghee
Ice-cream processing	1.74 kJ /100 L of ice-cream mix processed
Storing of products in cold store	2.67 kJ per 1000 L of milk storage

Table 4: Unit operation wise electrical energy consumptions in various product sections of dairy plant

Unit operation	Electrical energy consumed
Can washing	0.038 kWh/can
Crate washing	0.018 kWh/crate
Milk pasteurization	0.0989 kWh per 100 litre of milk
Cream pasteurization	0.512 kWh per 100 litre of cream
Cream separator cleaning	611.38 L/ cleaning
Peda processing	0.063 kWh/kg of milk processed
Paneer processing	0.008 kWh/kg of milk processed
Ghee processing	0.044 kWh/kg of butter
Butter processing	4.1 kWh per 100 litre of cream

3.2 CCPs determination for the plant and problem solving guidelines

A judicious analysis of the energy exhausting sequence in the selected multi-product dairy plant leads to a conclusion that, there was a few numbers of unit operations and equipments which consumed higher percentage of the total energy consumption in the plant per day. Hence, for effective energy management those processes or equipments were grouped into three classes (class A, B and C) based on the plot drawn by EMS.

Guidelines for improving the water utilization: As per the EMS, the CCPs for the cleaning purposes are categorized under three classes as follows: Class A: Cream tank cleaning, cream pasteurizer cleaning, RMTs cleaning, culturing tank cleaning and milk receiving section; Class B: Milk pasteurizer cleaning, aging tank cleaning, silos cleaning, crate washing section and flavouring tank cleaning; Class C: Tanker washing and cold storage cleaning.

As per the EMS, the CCPs for the processing purposes are categorized under three classes as follows: Class A: Paneer, peda and ghee section; Class B: Dahi; Class C: Ice-cream and lassi or mattha. Some ways for improving the utilization of water are given as: a) dairy staff should be instructed suitably to use the water judiciously and they must be trained properly for efficient cleaning and b) hose pipes should have small diameter as far as possible and a shut off valve can be attached at the end of hose pipe.

Guidelines for improving the steam utilization: As per the EMS, the CCPs for the steam requirement in cleaning purposes are categorized under three classes as follows: Class A: Aging tank cleaning, cream pasteurizer cleaning, crate washing section and culturing tank cleaning. Class B: Milk pasteurizer cleaning, cream tank cleaning and flavoring tank cleaning. Class C: Milk receiving section, RMTs cleaning, silos cleaning, tanker washing and cold storage cleaning. As per the EMS, the CCPs for the steam requirement in processing purposes are categorized under three classes as follows: Class A: Ghee, Peda, ice-cream and lassi/mattha section; Class B: Dahi and paneer section; Class C: Cream and milk pasteurization. As per Upadhyay (1998) [12], the following measures of energy conservation in boiler should be considered.

(a) Lagging and maintenance of hot surfaces of boilers and pipe-lines to minimize the heat losses. Boiler blow down should be done in optimum interval. All steam traps should be kept in the best condition.
(b) Fuel gas temperature should be maintained slightly above the dew point and continuously monitored to detect fouling of tubes. Burners should be checked to ensure proper atomization.
(c) Fuel temperature and pressure should be correct coming to burner. Revised fuel/air ratio should be maintained. Recovery of heat from the flue gases for heating feed water or combustion air.

Guidelines for minimizing the refrigeration load: As per EMS, the CCPs for the refrigeration consumption are categorized under three classes as follows: Class A: Raw milk chiller, milk and cream pasteurizer; Class B: Market milk chiller; Class C: Ice-cream and Paneer section. The following suggestion should be implemented to reduce the refrigeration load (Verma, 1976).

(a) Proper insulation of chilled water pipe and recirculation of chilled water.
(b) Selecting right temperature of storing the product and proper lagging of cold storage.
(c) Reducing reprocessing of milk.

Guidelines for reducing the electrical load: As per EMS, the CCPs for the electricity consumed in the utilities generation section are categorized under three classes as follows: Class A: Ammonia compressor and air compressor; Class B: Refrigerant booster, steam boiler, IBT agitator (7.5 HP), water jet pump and condenser pump; Class C: LDO reception and transfer pump, chilled water pump, tube lights, fan etc. As per EMS, the CCPs for the processing purpose are categorized under three classes as follows: Class A: Milk and cream processing section, butter making and packing section, milk reconstituted section, milk reception section and cold storage; Class B: Milk packing section, peda, dahi and lassi/mattha section; Class C: Ghee and paneer section. As per EMS, the CCPs for the administrative block, marketing section and security rooms as a whole for lighting, cooling and other purpose are as follows: Class A: Street lamp and split type AC; Class B: Air coolers and the rest of them are placed in Class C. As per, Bureau of Energy Efficiency the following measures are recommended to prevent excess electrical consumption

(a) Use solar lighting instead of halogen lamp in the campus. Also, install wall switches in all rooms, so that it can be turn off when not required.
(b) Use small motor for operation closer to the full load maximum efficiency point. Improve power factor by the use of synchronous motor or capacitors.

4. Conclusions

The developed energy management Software (EMS) has shown promising results in terms of energy monitoring and management. The equipment or processes listed in class A are the major energy consuming activities, hence all effort should be implemented to class A which leads to an effective energy management for the plant. After implementing the GUI and energy management total per day consumption of water, steam, refrigeration and electricity in the plant were optimized to 238.2 liters, 12.95 kg, 11.94 kJ and 5.98 kWh respectively per 100 L of milk. The cost of milk and milk products can be effectively reduced by utilizing the available energy efficiently and reducing the energy losses as per the daily data available in the developed EMS.

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