ENERGY MANAGEMENT IN A DAIRY INDUSTRY

SWAPNIL RATNAKAR MANE

MTech, Energy Science & Engineering, IITBombay, Mumbai

Abstract - With the increased industrialization more and more number of industries are setting up all over the world. For a developing country like India the number of industries setting up is overwhelming. The use of electricity is closely associated with the industrialization; hence to improve the efficiency of the industries which already are into existence seems to get first priority. This paper tries to find the scope available in an industry to use its resources in a proper manner by energy management. The in-depth analysis of a milk and dairy industry is shown in this context and one can use this as the basis to generate such over whelming results in different sectors. The scope of further improvements in energy utilisation with the latest researches that came to light is also discussed.

Keywords—Cogeneration, SCADA, Tri-generation

I. INTRODUCTION

Currently India produces around 123.7 million tones of milk every year and the same is processed in milk processing plants. (Source: Department of Animal Husbandry, Dairy & Fisheries, Ministry of Agriculture, GOI) Raw milk is collected from almost every part of the country and there is a wide scope for small scale processing plants. Milk can be converted to various dairy products such as cheese, curd, ice creams etc. As the per capita milk consumption in the country is rising the need to produce more amount of milk is gaining priority.

As the milk processing industries extend their production horizons the energy consumption in these and the upcoming industries will tend to rise. In accordance with the alternative and innovative means adopted for the milk processing plants one must also consider various energy conservation techniques in the existing plants in operation.

II. LAYOUT OF MILK PROCESSING PLANT

The layout of a milk processing plant depends upon the operations carried such producing pasteurized milk, cheese, curd, etc.

A typical milk processing plant receives raw milk from a collecting station through trucks and is stored in large tanks at the industry. It is then clarified and homogenized and moved to pasteurization. Milk is chilled upto 4 degree Celsius and then packed into cartons and dispatched for transportation.

Fig. 1 below shows a typical layout of a plant.

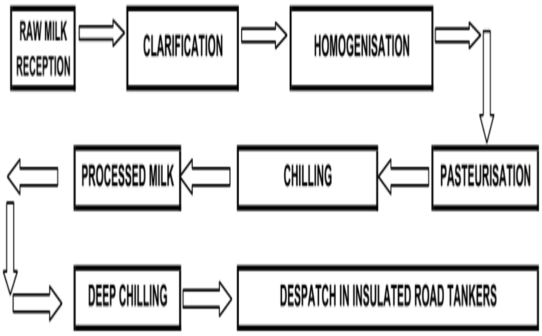
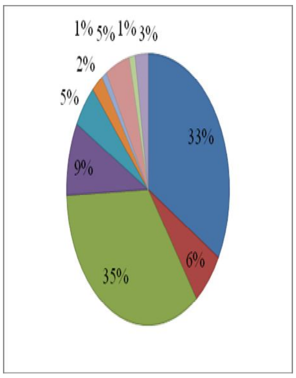


Fig. 1 Layout of milk processing plant

III. TOTAL ELECTRICITY CONSUMPTION



SECTION	TOTAL KWH	%
PROCESS	147384	33.35
PREPACK	28643	6.48
REFRIGERATION	152454	34.49
BOILER	38291	8.66
E.T.P	22626	5.12
PUMP HOUSE	10180	2.3
PRODUCT	4348	0.98
LIGHTING	21470	4.86
CANTEEN	5249	1.19
TETRAFINO	11323	2.56
TOTAL KWH	4441968	100.00

Fig. Sectoral Electrical Consumption [1]

IV. BOILER

The dairy has 1T/h rated low fire boiler which operates on almost full load producing 930Kg/hr steam.

The boiler uses furnace oil. The specification and the flue gas analysis are as shown in Table 1.

Description	Value
Steam Pressure	9 (kg/cm^2)
Steam Temperature	170(^0C)
Steam Enthalpy	2776.2KJ/Kg
Feed Water Temperature	80 (^0C)
Steam to Fuel Ratio	14(kg/kg)
A/F ratio	14:1
Description	Value
CO_2	14.5(%)
Oxygen	1.7(%)
Excess Air	13(%)
Flue Gas Temperature	250 (^0C)
Boiler Efficiency	84(%)

Table1. Flue gas analysis [2]

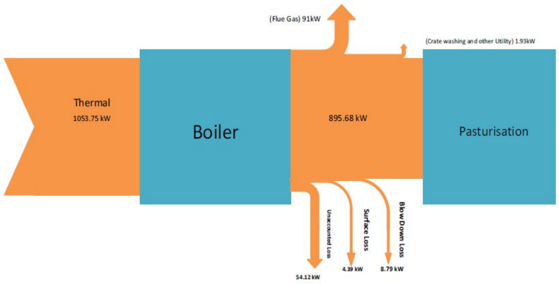


Fig. 3 Sankey Diagram for Boiler

With the data available from the industry the following energy calculations are made.

Operating Hours = 24 Hours

Production of Milk

Annual production = 13627071 Litres/month

= **18926.48 Litres/Hour**

Fuel Consumption

Furnace oil consumption= 66778 L/month

= 92.75 Lit/hr

Density of FO = 950 Kg/m^3

Mass of FO = 0.09275 X 950= **88.11Kg/hr**

Assume excess air = 13%

A/F = 14

Mass of air = 88.11 x 14 x (1+0.13)

= 1394Kg/hr

CV of FO = 10300 Kcal/kg

Mass flow rate of flue gases

= 1394 + 88.11

= 1482.11 kg/hr

Heat carried away by the flue gases

= (1482.11*1.005*(250-30)/3600)

= 91 kW

Blow down = 0.04 T/hr

Blowdown losses = 0.014*4.187*(180-30)

= 8.79 kW

Surface losses = 4.39 kW

Energy input of Fuel = 88.11*10300*4.18

= 3793488 kJ/hr

= 1053.75 kW

Efficiency of boiler = 85%

Energy output of fuel = 895.68 kW

Energy utilised by milk pasteurization

Specific heat of milk = 3.93 kJ/kgK

Density of milk = 1.03 kg/Litre

Energy for pasteurization= 3.93*1.03*(82-40)

= 170 kJ/Litres

= (170*18926.48)/3600

= 893.75kW

V. COGENERATION

Dairy industry requires both electricity and process heat. There is a chance of co-generation.

An existing boiler is replaced with the new high pressure boiler (η = 85%) and a back pressure turbine which strictly caters the process heat load.

m_s = 930 kg/hr

= 0.258 kg/s

Enthalpy at 40 bar 300^{0}c = 2962 KJ/Kg [3]

Enthalpy at 10 bar saturated = 2776.2 KJ/Kg[3]

(Power of turbine) P = 0.258 × (2962-2776.2)

(Electrical power output) P_E = 47.936 × 0.98($n_{generator}$)

= 47KW

Fuel consumption with cogeneration

F_C = 0.258 × (2962- 251.22)/10300×4.18×0.85

F_C = 76.76 Kg/hr

Fuel consumption without cogeneration

F_{NC}= 0.258× (2776.2-251.22)/ 10300× 4.18×0.85

= 71.25 Kg/hr

F_{PP} = 47/10300× 4.18×0.85

F_{PP} = 10 Kg/hr

Relative Fuel saving (R_F) = (71.25 +10) – 76.76/ (71.25 +10)

= 5.54%

FCP (fuel chargeable to power) = 0.1147 Kg/KWh

Heat rate of Co-generation =0.1147×10300×4.18 KJ/KWh

=4946.56 KJ/KWh

Heat Rate of power plant = 3600/0.4

= 9000KJ/KWh

The co-generation system shows relative fuel saving and heat rate of co-generation is less than the heat rate of power plant. Hence cogeneration is seen to be feasible but it has following limitation:

The Power generation is so small hence it is difficult to get the generator of such a small capacity. Even if we get the generator then scale of pay is very high hence it is not that affordable.

VI. WASTE HEAT RECOVERY

Since there are several limitations associated with the co-generation system. Hence we can also use the option of WHR (waste heat recovery) because exhaust gases are at high temperature (250^0c). Hence by retrofitting the economizer that can extract heat from flue gases which can be used for the preheating the boiler feed water. The proper calculations are as follows:

Boiler uses furnace oil which has A/F ratio = 14

Fuel rate = 71.25 Kg/hr

Excess air = 13%

Air rate = (1+0.13) ×14×71.25Kg/hr

= 1188.45Kg/hr

So, 1188.45×1.005× (250-160)

= 930 × 4.18× ΔT

ΔT = 27.64^0c

Fuel saving

$m_f \times 10300 \times 0.84 = 930 \times 27.64$

m_f = 3.2Kg/hr

Sr. No.	Recommended Measures	Fuel saved Litre/Month	Capital Cost (Rs)	Savings (Rs/Month)	Simple Payback Period (month)
1.	Retrofit Economizer for the Waste Heat Recovery from Boiler	2422	19,00,000	96870	20

VII. REFRIGERATION

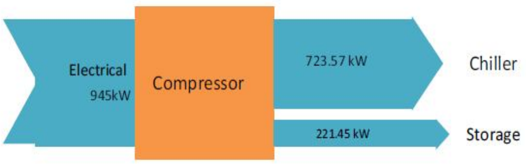


Fig. 4 Sankey Diagram for refrigeration

Energy for chilling = 3.93*1.03*(40-6)

= 137.63 kJ/Litres

= (137.63*18926.48)/3600

= 723.57 kW

Refrigeration load = 270TR

Electrical load = 270*3.5 = 945kW

For Storage = 945-723.57 = 221.43kW

The dairy has refrigeration load of 270 TR. It uses 3 screw compressors and 1 reciprocating compressor with ammonia (NH_3) as refrigerant. About 35% of the electrical load is utilised in refrigeration. The plant incorporates an ice-bank maintained at 0^oC by controlling the compressor load. Presently, there is no integration between the process plant and refrigeration plant and the controlling is done manually. This variation is clearly seen from this given graph:

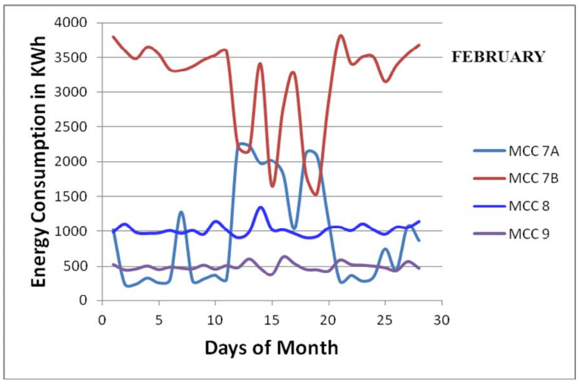


Fig 5. Energy consumption for February

Using the SCADA system we can integrate the process and refrigeration systems this will tend to reduced variation.

De super heaters

At the outlet of the compressors the temperature is around 85^oC to 95^oC which is very high as compared to R-22 refrigeration system. This system can be utilized to heat boiler feed water. This gives the saving in terms of fuel. The calculation is given as follows:

$270 \times 210 = m_R \times (h1 - h3)$

or, $180 \times 210 = m_R \times (1457.81 - 350)$

or, m_R = 51.18 kg/min

= 3071 kg/hr

$m_R C_P \times (95\text{-}60) = m_w \times C_{pw} \times (\Delta T)$

or, $3071 \times 2.176 \times (95 - 60) = 10^3 \times 4.187 \times (\Delta T)$

or, $\Delta T = 56^oC$

saving:

$10300 \times 4.18 \times 0.84 \times m_f = 10^3 \times 4.187 \times 56$

or, m_f = 6.48 kg/hr

or, m_f = 4665.6 kg/month

saving = 186624 Rs/month (fuel cost = 40 Rs/kg)

Sr. No.	Recommended Measures	Fuel saved Litre/Month	Capital Cost (Rs)	Savings (Rs/Month)	Simple Payback Period (month)
1.	Condenser heat can be recovered in the Heat Exchanger to preheat the water ($\Delta T = 56°C$)	4665.6	11,50,000	1,86,624	6

Table 3. Refrigerator Energy management

Partition in the cold Storage:

Month	Milk processed (litres)
Aug 12	15183797
Sep 12	13851051
Oct 12	14191597
Nov 12	11843581
Dec 12	12975300
Jan 13	13717100

Table 4. Monthly milk production [5]

6 months average
= 13627071/month
= 439583/day
= 146527.65 litres/shift
~ 146528 litres/shift(10% less in product)
~ 131875 litres/shift (storage required)

Without partition

60 TR x 3.5 = 210 KW
= 5040 KWh (24 hrs operation)

With partition
37.5 x 3.5 x 8 hrs = 840 kWh/day
60 x 3.5 x 16 hrs = 3360 kWh/day

Total =4200 kWh/day
Savings = 630 kWh/day
= 630 x 30 x 6.3 kWh/month
= 119070 Rs/month

Sr. No.	Recommended Measures	Fuel saved Litre/Month	Capital Cost (Rs)	Savings (Rs/Month)	Simple Payback Period (month)
1.	Cold storage is not utilized to the fullest hence the option of partition is evaluated	18900	1,50,000	1,22,000	2

Table 5. Cold storage Energy Management

VIII. ELECTRICAL

Motors

During inspection we found that the motors on the condenser 2 and 3 are working on the part load condition and after discussing to their staff we noticed that even pumps are not operating up to the mark.

Motors/Pumps	Rated Power(hp)	Actual Power(kw)	% Load
Pump-3 on Condensor-2	12.5	5.4	52.1
Pump-2 on Consensor-3	5.0	2.5	57
Pump-1 on Condensor-3	12.5	7.4	71.4

Table 6. Specifications of motors

These motors can be replaced by small capacity motors depends on their individual maximum demands or they can be retrofitted with the VFDs.

Lighting

The dairy has around 95 number of tube lights which have magnetic ballast. They can be replaced by electronic ballasts which give greater energy savings.

Rating of tube light	36 KW
No	895
Electric consumption with magnetic ballast	51 W
Electric consumption with electronic ballast	31 W
Operating hours (approx.)	250 hr/month
Savings	4475 kWh/month

Table 7. Lighting Load Specifications

Sr. No.	Recommended Measures	Fuel saved Litre/Month	Capital Cost (Rs)	Savings (Rs/Month)	Simple Payback Period (month)
1.	Replacing magnetic ballast (51 W) of The tube lights by Electronic Ballast (31 W)	4475	29,000	400000	13

Table 7.1 Electrical energy management (Tubelights)

The dairy has certain numbers of mercury vapour lamps which can be replaced by a metal halide lamp. Thus, about 40% saving is possible.

Rating of Hg vapour lamp	125 W	250 W
No.	50	88
Period	12 hr/day	11 hr/day
Rating of metal halide lamp	80	120
Saving	810 kWh/month	4118.4 kWh/month

Table 7.2 Electrical energy management (Lamps)

Compressor

The dairy requires compressing air for actuating valves blowers etc. the specifications of compressor are followed:

Capacity	390 Cfm
Operational	170 Cfm
Compressed air required	103 Cfm
Electricity consumptions	0.2 KW/Cfm
Loading pressure	7.52 kg/cm^2
Unloading pressure	8.5 kg/cm^2

Table 7.3 Compressor Specifications

The operations of compressor are as followed:

Loading period	10 hrs/day
Unloading period	14 hrs/day
Unload power	12.63 kW
Total power loss	5313.2 kWh/month

Table 7.4 Loading Unloading of Compressor

This power loss can be saved by retrofitting VFD (variable frequency drive) on compressor.

Sr. No.	On loading period Hour/day	Unloading Power kWh/month	Total Saving Rs/month	Capital Cost Rs	SPP Month
1.	14	5313	34317	300000	9

Table 7.5 Electrical energy management (Compressor)

IX. RENEWABLES

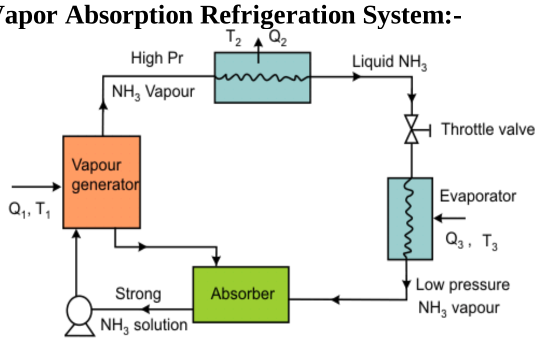
The plant has 25 flat plate collectors installed to preheat the boiler feed water. During our inspection we found that the outlet temperature of outlet is 45^0C. The actual claimed temperature at outlet is around 80^0C. The reasons for poor efficiency can be poor maintenance. It is hereby recommended that the collectors should properly clean regularly. Also the installation of collectors away from the boiler house which causes loss through the pipes. Hence it's recommended to have good insulation on delivery side and if possible then to install collectors on boiler house itself.

Even if the company has bio-gas digester and boiler, it is not in working condition due to the leakage of the tank that can be repaired which will give great saving. Because even the biogas having calorific value up to 5000kcal/kg hence if this plant can bring in to working condition it can be the best feasible alternative for furnace oil.

X. FUTURE SCOPE OF IMPROVEMENT

The Dairy industry is going to grow in the future. It's a one of the industry which requires process heating, refrigeration cooling and electricity loads. Hence this is an industry which has a huge scope of tri-generation. Here are the some of the feasible options for the tri-generation

Vapor Absorption Refrigeration System:-



The main problem regarding to the cogeneration is its small capacity. The small capacity was due to we were only catering the process heat load now if we install the VARS then the heat required in the generator will be also taken by the turbine outlet steam. The turbine exhaust now will be using for three purposes:-

1) Process Load
2) VARS Generator
3) Bleed of steam can be used for regeneration or in De-aerator.

If we consider a single pass liquid ammonia system having COP=0.7 then to fulfil the total requirement of refrigeration load (270TR) the system will require 1350kW of heat. At 10 bar saturated the steam required will be 1750 kg/hr. The process requirement is 1T/hr. By using high pressure boiler and bleeding of some steam we can produce electricity around 1 MW. Another advantage of this system is the part of heat which is supplied to generator can be recovered from absorber at lower temperature but it can be used for pre heating water or oil.

(Sample calculations)-

Assuming boiler is operating at 40 bar and 700^0C

$h_g = 3904$ kJ/kg $\qquad h_{out} = 2776$ kJ/kg

To produce electricity of 1 MW the steam flow rate required = 3257 kg/hr.

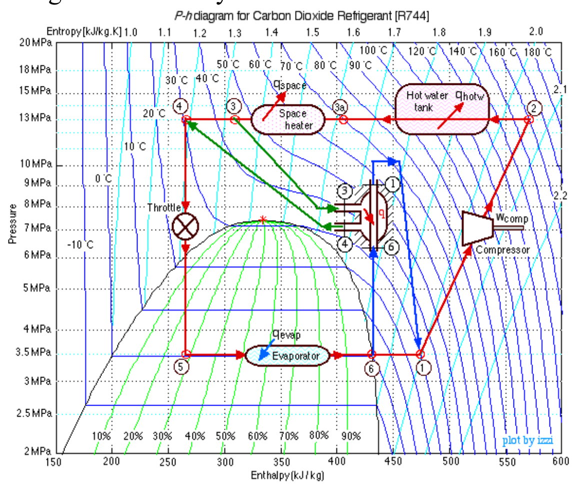
…… (Efficiencies of turbine and generator are 75% and 98% resp.)

Mass to be bleed off= 3257-1000-1750= 507 kg/hr

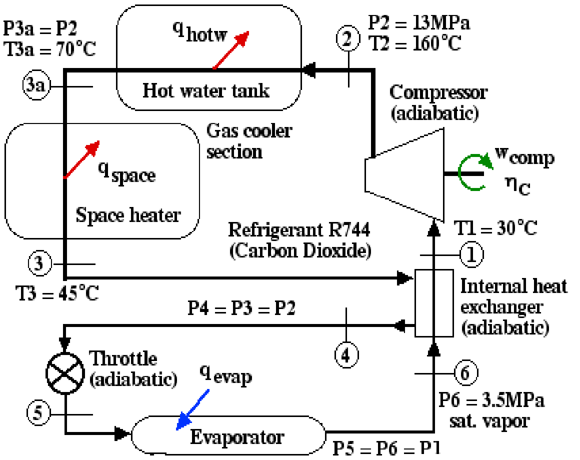
This mass can be used for regeneration or can be used in de-aerator. Since dairy industry has quiet huge amount of waste heat hence option of VARS seems to be feasible in future.

Refrigeration Using Carbon Dioxide:-

Among all the refrigerants the CO_2 is having lowest GWP. The CO_2 refrigeration cycle is a Trans-critical cycle which is capable to fulfill the cooling and heating demands. Since it's a Trans critical cycle it can give evaporator temperature about 1^0C and condenser temperature around 170^0C these are the desired temperatures for the process heat and refrigeration in dairy.



The main problem associated with this cycle is the compressor works at higher pressure ratio and high pressure itself. It consumes more power as compared to other refrigeration cycles, but by supplying power at single place we can achieve both heating and cooling unlike other refrigeration cycles.



Instead of using electricity one can use DG sets for the compressors with the direct appropriate coupling which can be helpful to reduce the motor and generator losses. Though the capital cost of this refrigeration system will be high because of high pressure pipe line and compressor it will give the good payback period.

Safety

The dairy uses ammonia as a refrigerant but it has no ammonia detector as ammonia is hazardous when its level goes above 1ppm it causes irritation of eyes and nose. If level goes above 25ppm it can cause headaches, nausea, and intense burning of the eyes, nose, throat, and skin. Exposure to high levels of ammonia will lead to permanent damage of eyes and lungs. Also ammonia is inflammable gas. Hence it's strongly recommended to take safety measures to prevent any catastrophe.

CONCLUSION

Dairy industries exist in every corner of the world and they have a considerable share in the country`s economy. The share of electricity consumption in this sector is dominant too. The calculations and results obtained from this study may prove helpful to develop a model based approach to determine the energy saving capabilities in the sector.

REFERENCES

[1] Data collected through Industry Visit and data log sheet available with the anagement.

[2] Data collected through Industry Visit and data log sheet available with the anagement.

[3] Steam Tables, Mathur & Sharma.