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Energy Conservation Measures in Dairy Industries

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Abstract: - In this research paper certain energy conservation measures in dairy industries have been discussed in the field of refrigeration and thermal energy conservation. The energy saving devices considered in this research work are waste heat recovery systems, economizers, cogeneration systems, vapour absorption system. Hence, realizing the importance of the need for energy conservation in industries on a long term basis, this paper provide us necessary real life solutions for the dairy industries to save considerable energy. Diary industries may follow the energy conservation techniques as given in this paper. So in order to solve the energy crisis problem and meet the energy demands, it is necessary to perform audits, so that every industry utilizes its maximum energy available and runs efficiently.

Key-Words: - boiler, conservation**,** economizer, energy, heat recovery system, refrigeration

1 Introduction

Energy is a many-dimensioned thing. It is visible only through what it does and what it was before it became energy. It is a crucial input in the process of economic, social and industrial development. Besides the other three classical factors, that is land, capital and labour, energy is of vital importance in the context of development.

1.1 Energy Crisis

Today the world faces an energy problem, which can be identified as a developed dependence on oil and gas. The problem grew out of the industrial revolution and the successes of a scientific age. Petroleum was only one of many energy resources in this evolutionary process. We have known almost from the beginning that oil is not infinitely available but this fact had no significance. Another energy source would replace oil. This was the accepted knowledge before there was any scientific basis for believing that atomic energy could be harnessed and now we are producing a substantial amount of this energy. Why then a fear of a developing energy crisis at this point in history? The answer lies in this numbers the quantities in the remaining oil and gas resource, the time delay and limitations of the present atomic energy development, the human life spent and the human population. A second major contributor is our developed humanity. So in order to solve the energy crisis problem and meet the energy demands, it is necessary to perform audits, so that every industry utilizes its maximum energy available and runs efficiently.

2 Problem Formulation

The energy conservation must be recognized as a new source of energy begin and friendly source. The industries cannot control the rise of energy prices but can definitely control the consumption of energy by adapting various energy conservation techniques in their plants.

Energy plays a major role in processing milk and milk products. In a dairy, primary energy sources such as furnace oil, etc are used in boiler for generating steam which in turn is used for heating applications like pasteurization, evaporation, drying of milk.

Electricity is another major energy input, which is utilized for refrigeration, and motive loads.

The cost of energy in processing milk in a dairy is substantial. Nearly 30% of overall manufacturing cost is spent on purchase of furnace oil, electricity. For example in a liquid milk cum product Dairy plant, processing about 2.5 lakhs litre of milk/day, the total annual energy bill would be about Rs.70 lakhs. The share of cost between the thermal energy and electrical energy is about 60% and 40% respectively. Therefore energy conservation in a Dairy plant has a substantial impact in reducing the cost of processing milk.

In this regard, two major areas of energy conservation have been taken. They are

1. Energy conservation in fuel fired equipment (Boiler)
2. Electrical energy conservation in refrigeration system.

3. Problem Solution

3.1 Scope for Electrical electrical energy conservation in refrigeration system

Chilled water is used for cooling pasteurized milk and other dairy products and also used for precooling incoming milk and holding or lowering the temperature in milk storage tanks. In the dairy, chill water is produced at the cost of electrical energy by vapour compression system. In order to cut down the electrical expenses, utilizing the waste heat source available at powder plant, a vapour absorption system is designed to produce chill water. Thus electrical energy is conserved.

3.2 Energy conservation in boiler

Currently the condensate from power plant is used for feed water heating. So to replace it and efficiently use the exhaust gas from the boiler, an economizer is designed for feed water heating, thus consuming the fuel supplied.

3.3 Scope of energy conservation in dairy industries

3.3.1 Waste heat sources

The major waste heat sources in the dairy plant are ;

1. Steam condensate at a temperature of 90-1100 °C and at a flow rate of 1200 Kg/hr from the Drier of the powder plant.
2. Exhaust gas at temperature of 2350 °C from the boiler.

The steam condensate from the drier section of the powder plant has sufficient amount of heat for the generator section to separate water vapour in lithium bromide vapour absorption system.

The exhaust gas at the temperature of 2350 °C can be utilized to preheat the boiler feed water.

3.4 Introduction to vapour absorption system

In the vapour absorption system, compression process of vapour compression cycle is eliminated. Instead following three processes are carried out.

1. Absorbing of vapour into water.
2. Pumping this solution to a high pressure cycle.
3. Producing vapours from solution by heating

3.4.1 Construction:

The vapour absorption system also consists of a condenser, an expansion value and an evaporator as a vapour compression system. They perform the same function as they do in vapour compression system. In addition, this system has an absorber, a heat exchanger and a rectifier.

3.4.2 Working:

3.4.2.1 Water-lithium bromide system:

Water-lithium bromide systems are used extensively in air conditioning and other high temperature applications, but with water as the refrigerant, they are not suitable for use in any application where the evaporator temperature is below 0 ºC . Lithium bromide in its crystal form is a hygroscopic salt and in solution extensive deliquescent characteristics, which means it has a high affinity for water vapour. This unique characteristic makes it possible to use it as absorbent in the chilled water production system, with water as refrigerant. Since the absorbent is non-volatile only the pure refrigerant (water) vapour is distilled off in the generator. The components of the lithium bromide-water absorption system are shown in schematic diagram in figure. The lithium bromide-water absorption system operates under a high degree of vacuum. The pressure in the condenser and generator is 42.7 mm of mercury while that of the evaporator and absorber is 6.2 mm of mercury. The heat of steam condensate from drier plant and the powder plant section is transferred to the pump lithium bromide-water mixture. Thus water vapour is distilled off and it leaves the generator in a super heated condition at 1050ºC . The lithium bromide returns to the absorber. A water cooled condenser condenses heated vapours and the liquid leaves the condenser at 350 °C. A capillary tube maintain the pressure differential between the condenser and evaporator and hence the liquid leaving the capillary tube is saturated. The latent heat of vaporization of the refrigerant (i.e. water) produces the cooling effect and the temperature of the evaporator is 40°C . The liberated vapour get dissolved in the lithium bromide in the absorber. The lithium bromide-water mixture is again pumped to the generator. Thus cycle goes on.

3.5 Concentration and heat distribution in each component

The concentration calculation is to determine the mass flow rates and the enthalpies of the refrigerant-absorbent mixture entering and leaving each component of the system. By mass balance the distribution of heat (heat rejected or absorbed) in each component can be manipulated. For the lithium bromide - water combination the temperature for various components, for the chill water production unit is normally chosen as furnished below:-

Generator temperature = 1050°C .
Condenser temperature = 350°C
Evaporator temperature = 40ºC
Absorber temperature = 350 °C

The pressure corresponding to the condenser and evaporator are,

Evaporator pressure = 6.2 mm of Hg.
Condenser pressure = 42.7 mm of Hg.

In the vapour absorption cycle there will be two pressure region. On the high pressure and the other low pressure region. The generator and condenser constitute the high pressure region and operates at 42.7 mm of Hg. While the evaporator and the absorber play for the low pressure region and operate at 6.2 mm of Hg. Main assumption is that there is negligible pressure drop throughout the system. If the concentration of the water (refrigerant) is greater when compared to mass of lithium bromide (absorbent), then this mixture is called strong solution. Weak solution is one whose concentration of water is minimum in the mixture of lithium-bromide water. The conditions of the liquid and vapours at each component are furnished below:-

The liquid (water) leaving the thermostatic expansion value is the saturated liquid (5). This saturated liquid (5) enters the evaporator forming into a saturated vapour(6). This saturated the strong solution. The strong solution pumped to generator is separated by the heat supplied and the pure refrigerant the super heated water vapour (3) is passed to the condenser where the latent heat of condensation takes place changing the phase from vapour to liquid. The thermostatic expansion value reduces the pressure to a saturated liquid vaporizes as soon as it enters the evaporator. The concentrations and enthalpies for the corresponding temperature and pressure are picked out from the concentration-enthalpy (H-C) chart of Aqua lithium bromide solution. From these values the mass balance and the concentration balance is done and the mass flow rates of the refrigerant at all points of the system is calculated. Considering each component of the system the heat rejected or absorbed in each component can be manipulated by the energy balance:-

3.6 Design of Vapour Absorption System

Heat source available in drier section:

Condensate of steam : 90 to 1100 °C at 1.5 to 2 kg/cm^2

Mass flow rate : 1250 kg/hr .

3.6.1 Design parameters

Generator temperature = 1050°C.

Condenser temperature = 350°C.

Evaporator temperature = 40°C.

Absorber temperature = 350°C.

3.6.2 Heat Available from Waste Heat Sources, Qg

Qg = M (Hsteam- Hwater)

= 1250 / 3600 (2243.6 - 209.3)

= 706.35 KJ/s

3.6.3 Concentration of Weak Lithium Bromide Solution from Absorber, C1

This is obtained by intersection of 308° K and 6.2 mm pressure line in the

From the H-C chart. C1=0.62 H1=-160KJ/Kg

3.6.4 Concentration of Lithium Bromide Solution from Generator, C7,C8

This is obtained by intersection of saturation pressure corresponding to 378 °K of the condenser saturation state.

C7=C8=0.67 H7=-20 KJ/Kg

Enthalpy of Liquid Leaving Condenser,

This is obtained from zero concentration and saturation pressure,

C4 = C5 = 0 H4 = H 5 = 146.6 KJ/Kg.

Enthalpy of Water Leaving Evaporation, H6

This is obtained from zero concentration and saturation steam table.

C6 = 0 H6 = 2509 KJ/Kg.

Enthalpy of Vapour leaving generator, H3 :-

This is obtained from H-C chart corresponding to 42.7 mm of Hg.

C3 = 0 H3 = 2670 KJ/Kg.

A 100 TR refrigeration system is designed, M6

Mass of refrigerant flow, M6 = TR / (H6-H5)

= 100 * 3.5 / (2509-146.6)

= 0.148 Kg / s

= 8088 KJ / min.

Making Mass Balance for Absorber , M7

Qa = Heat rejected by absorber, M7

M6C6+M7C7 = M1C1

8.88 * 0 + M7 * 0.62 = M1*0.62 , M6 , M1

0.62 M7 = 0.62 M1

M1 = 1.08 M7

QA

Total Mass Flow, M1

M6+M7 = M1

8.88 +M7 = 1.08 M7

M7=8.88 / 0.08

M7=111 Kg / min

M1=1.08 * M7

M1=1.08 * 111

=119.88 Kg / min

Using Generator as Control Volume , Qg

Qg - Heat supplied to generator.

M2H2 + Qg = M3H3+M7H7

Qg = M3H3+M7H7-M2H2 Qg

= 8.88 * 2670 + 111 * (-20) - 119.88 * (-160)

= 40670.4 KJ / min

= 677.84 KJ / s.

Making Heat Balance of Absorber, QA

M6H6 + M8H8 = QA+M1H1

QA = M6H6+M8H8-M1H1

= 1.85 * [-20] + 0.148 * 2509 - [1.998 * (-1.60)]

= 654.012 KJ / s

Making Heat Balance of Condenser, QC

Qc+M4H4 = M3H3

Qc = M3H3-M4H4 M3

= 0.148 * 2670 - 0.148 * 146.6

= 373.46 KJ / s

Heat given to generator, Qg = 677.84 KJ / s M4

Heat given out in evaporator, Qev = 100 * 3.5 =350 KJ/ s

Heat supplied to system, = Qg + Qev

= 677.84 + 350

= 1027.84 KJ / s

Heat rejected in system, = Qc – Qa

= 373.46 – 654.012

= 1027.47 KJ / s

Heat supplied to the system = Heat rejected to the system

Refrigerating effect, = 100 * 3.5

= 350 KJ / s

Actual C.O.P = Qc / Qg =350 / 677.84 = 0.516

3.7 Economizer

3.7.1 Waste Recovery from the Furnace Flue Gas

In any industrial furnace, the products of combustion leave the furnace at a temperature higher than the stock temperature. Sensible heat losses in the flue gases while leaving the chimney, carry 35 to 55 % of the heat input to the furnace. The higher the quantum of excess air and the flue gas temperature, the greater would be the waste heat available. The sensible heat in the flue gases can be generally salvaged by many methods. Some of these are

1. Change the pre-heating.
2. Pre heating of combustion air.
3. Pre heating of feed water.
4. Steam generation through waste heat from boiler, gas turbine systems, Vapour absorption Refrigeration system.

The economizer is a feed water heater driving heat from the flue gases discharged from the boiler. This depends on the gas temperature out of the boiler and feed water temperature to the boiler. Economizer consists of a group of the steel tubes located in the main flue between the boiler and the chimney. The waste flue gases flow outside the economizer tubes and heat is transferred to the feed water flowing inside the tube. Cost of the economizer depends on the total gain in efficiency and also boiler size, type of fuel used and exhausts gas temperature.

3.7.2 Design Requirements for an Economizer

1. It must be able to extract maximum possible heat from exhaust gas.

2. The gas side pressure losses should be minimum to reduce the running expense of I.D. fans.
3. There must be uniform water flow to avoid the steam formation in the economizer.
4. The pressure loss of water side should be minimum to reduce running expenses of the pump.

3.7.3 Corrosion prevention of economizer

Corrosion and prevention are very important for safe and efficient working of the economizers. External corrosion of the economizer tubes is very serious due to sulphur content in the exhaust gas. Sulphurous acid created in SO^2 is dissolved in free moisture in the flue gas, sulphur trioxide may combine with superheated water vapour to form H^2SO^4 at the dew point. The reaction usually occurs between 1150°C to 1400°C under normal boiler operating conditions. Acid corrosion also damages steel stuck if the temperature of gas entering the stack falls below its dew temperature. Proper stack insulation to keep the wall temperature above the acid dew point is the first step in minimizing the problem. Corrosion resistant material or high temperature corrosion resistant linings are also used.

3.7.4 Thermal design parameters

The following parameters are to be designed while designing economizer.

1. Tube diameter.
2. Tube thickness.
3. Tube length.
4. Tube pitch.
5. Tube side pass
6. Tube count
7. Shell diameter.

3.7.5 Design Procedures of Economizer

1. Calculate the mass flow rate of exhaust gas.
2. Heat duty required.
3. Calculate the mass flow rate of water.
4. Calculate Logarithmic Mean Temperature Difference [LMTD]
5. Required heat transfer area.
6. Calculate the number of tubes.
7. Actual area required.
8. Calculate the tube shell side heat transfer co-efficient.
9. Calculate the shell side heat transfer co-efficient.
10. Calculate the overall heat transfer co-efficient.

3.7.5.1 Design parameters

Flue gas inlet temperature, tg1	= 2350°C
Flue gas outlet temperature, tg2	= 1850°C
Water inlet temperature, tw1	= 300°C
Water outlet temperature, tw2	= 600°C
Overall heat transfer co-efficient, U	= 115 W / m^2 K (from table)
Specific heat of flue gas, Cpg	= 1.1095 KJ / Kg °K
Specific heat of water, Cpw	= 4.1868 KJ / Kg °K
Flow rate of fuel, mf	= 0.24 m^3 / hr
Density of air, m3 air	= 1.205 Kg / m^3
Density of fuel, □f	= 0.92 Kg / m^3
Length of tube, L	= 2400 mm
Inner dia. of tube, D1	= 21.18 mm
Outer dia. of tube, D2	= 25.40 mm
Fouling factor of water, Fw	= 254 mm
Fouling factor of water, Fw	= 0.00036 m^2 °K / W
Fouling factor of flue gas, Fg	= 0.00018 m^2 °K /W

3.7.5.2 Properties of cold water taken from data book

Film temperature of water at 450°C.

Prandtl number, Pr = 4.01
Thermal conductivity, K = 633 x 10-3 W / m °K
Kinematic viscosity, = 0.523 x 10-6 m^2 / s
Density of water, =1000 Kg / m^3
Film temperature of exhaust gas at 2000C.
Prandtl number, pr = 0.67
Thermal conductivity, K = 40.12 x 10-3 W / m °K
Kinematic viscosity, =32.188 x 10-6 m^2 / s
Density of gas, = 0.784 Kg / m^3

3.7.6 Calculations

1. Mass flow rate of exhaust gas = mg= Mass of air + Mass of fuel
= (Volume of air x density) +
(Volume of fuel x density of fuel)
= (6000 x 1.205) + (0.24 x 0.92)
= 7230.2208 Kg / hr
= 2.0084 Kg / s

2. Heat duty, Q = mg Cpg(tg1-tg2) = 2.0084 x 1.1095 x (235-185)
=111.416 KJ / s
= 111.416 KW
Assuming effectiveness = 90%=0.9
Q = 111.416 x 0.9 =100.274 kW

3. To find mass flow rate of water:-
Heat ,Q = mw Cpw(tw2-tw1)
100.274 = mw x 4.1868 (60-30)
= 125.604 mw
= 100.274 kW
mass of water required = 0.798 Kg / s
125.604
= 2874 Kg / hr

4. To find LMTD of heat transfer: -
LMTD of heat transfer, Tm = $\frac{T1 - T2}{\text{Loge } (T1/T2)}$
Where ,T1 = tg1-tw2
=235-60 = 1750°C
T2=tg2-tw1
=185 – 30 = 1550°C
Tm = $\frac{175 - 155}{\text{Loge } (175 / 155)}$
= 164.80 °C

5.To find required heat transferred area (A): -

Heat transfer area, A = Heat duty / Overall heat transfer co-efficient x LMTD

$$= \frac{Q}{U.\ Tm}$$

$$= \frac{11.416 \times 103}{115 \times 164.8}$$

$= 5.879\ m^2$

6.To find number of tubers required (n): -

Number of tubes required in heat exchanger, n

$$n = \frac{\text{Required heat transferred area}}{\text{Contact area of each pipe}}$$

$$n = \frac{A}{D0\ L} = \frac{5.879}{3.14 \times 0.0254 \times 2.4}$$

$= 30.69$

Nearest standard number of tubes = 32 numbers

7. To find actual area required: -

Actual area required = Number of tubes x contact area of each tube

$= n\ \pi\ D0\ L$

$= 32 \times \pi \times 0.0254 \times 2.4$

$= 6.128\ m^2$

8. To find the tube side heat transfer co-efficient: -

Velocity of Water (Vw) = Mass / density of water x Number of tubes x cross sectional area of contact in tubes

$$= \frac{m}{(\rho \times n \times .\ A)}$$

$$= \frac{0.798}{(1000 \times 32 \times ¼ \times \pi \times 0.021182)}$$

$$= \frac{0.798}{11.274}$$

$= 0.07078\ m / s$

Reynold's number Red $= Vw \times Di / \gamma$

$$= \frac{0.07078 \times 0.02118}{(0.523 \times 10^{-6})}$$

If the flow is turbulent

According to Dittus – Boelter equation

Nusselt number, Nu = 0.023 x Red 0.8 x Pr 0.4

= 0.023 x 2866.390.8 x 4.010.4

= 23.38

Heat transfer co-efficient,

$$Hi = \frac{Nu \times k}{Di}$$

$$Hi = \frac{23.38 \times 633 \times 10^{-3}}{0.02118}$$

$= 698.7656\ W / m^2$

9. To find the shell side heat transfer co-efficient: -

Velocity of the flue gas, Vg=mg / ρg A

$$= \frac{2.0084}{(0.784 \times ¼ \times \pi \times 0.2542)}$$

=52.99 Kg / s

Reynolds's number Re = vg x D0/γg

$$= \frac{52.99 \times 0.0254}{32.188 \times 10^{-6}}$$

= 41815.15

If the flow is staggered,

For the tube banks of 10 rows,

Sn / D0 = 2.12

Staggered pitch , 1.5

= 0.452, n = 0.568

Nusselt number, Nu=C x Ren x Pr0.33

= 0.425 x 41815.150.568 x 0.670.33

=166.98

Shell side heat transfer co-efficient,

$$H0 = \frac{Nu \times k}{D0}$$

$$= \frac{166.98 \times 40.12 \times 10^{-3}}{0.0254}$$

$= 263.747\ W / m^2$

10.To find overall heat transfer co-efficient:

Overall heat transfer co-efficient,

$$U = \frac{1}{\frac{1}{h0} + Fg + \frac{D0}{2K}\ln(D0/Di) + \frac{D0}{Di} Fw + \frac{D0}{Di} \cdot \frac{1}{hi}}$$

$$U = \frac{1}{(3.79x10\text{-}3) + 0.00018 + (5.75x10\text{-}5) + (4.32 \times 10\text{-}4) + (1.716 \times 10\text{-}3)}$$

$= 161.924\ W / m^{2\circ}K.$

3.8 Cost Economic Analysis

In order to calculate the power saved by vapour absorption system over vapour compression system, it is necessary to find load calculations.

Capacity = 100TR
Condensing temperature =350 °C
Evaporating temperature = 40° C

Now heat removed =100 x 3.5 = 350 KJ / s (□1TR=3.5 KJ / s)
Work input to compressor = 48.5 kW
Number of units consumed / day = 48.5 x 24
= 1164 units / day
Number of units consumed/month = 1164 x 30
= 34920 units
Power bill per unit = Rs.2.00
□Power bill for a month = 34920 x 2.00
= 69840.00

Amount spent for electrical energy in a year = 69840 x 12 = Rs.8,38,080.00 (8.38 Lakhs)

But approximate cost required to install vapour absorption system by utilizing the waste heat = Rs. 20,00,000.00 (Twenty lakh only)

This cost can be recovered by saving the electric bill with in a period of 3 years and 3 months

Similarly by using economizer, saving can also be made in cost of furnace oil.

In case of economiser a maximum of 20% fuel can be saved if the boiler runs effectively. It is also found that about 1% of fuel is saved for every 60°C raise in temperature. By using this design, it is able to save 4% to 5% of fuel.

4 Conclusions

The statements entitled " The Cheapest energy is saved" and "Power saved is power produced" clearly, imply the necessity of energy conservation in this global arena. So in this regard certain energy conservative measures have been suggested in the field of refrigeration and thermal energy conservation in diary industries. Diary industries may follow the energy conservation techniques as given in this paper to conserve as much as energy possible. The energy saving devices discussed are waste heat recovery equipments like economizer and cogeneration systems and vapour absorption system.

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References:

[1] Sachdeva, R.C., Book entitled "*Fundamental of Engineering Heat and Mass Transfer*" , pp 201-245,

[2] Myer Kutz , Text Book entitled *" Mechanical Engineering Hand Book"* ,23-87.

[3] Kotendaraman, C.P., and Subramaniam .S., Text Book entitled "*Heat and mass transfer data book",65-190.*

[4] Wood Heart and Willcox, Text book entitled "*Modern refrigeration and Air-Conditioning, 68-209.*"