A Review on Exergy Analysis of a Milk Powder Production System

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Abstract- **Milk is an essential component of daily life and it is used in various forms like curd, cheese, butter, milk powder, ghee etc. Among them, milk powder is dried form of milk and popular for its longer shelf life and can be stored at ambient temperature. Milk powder manufacturing unit consists of various thermal processes like pasteurization, evaporation, drying and these processes consume very high energy. In last decade energy has become a topic of major concern due to various reasons like hike in price of fossil fuel, strict emission standards and increase in energy consumption. The aim of the study is to apply a thermodynamic analysis including comprehensive exergy analysis by using different performance parameters such as exergy efficiency, exergy destruction rate for the milk powder production system. Here in this paper analysis of milk powder manufacturing process is reviewed using energy and exergy tools.**

Index Terms- **Exergy analysis, pasteurization, evaporation.**

I. INTRODUCTION

Due to the high energy consumption and sustainable development, a lot of attention has been given to find the most cost-effective and ecofriendly ways of energy utilization. This can be achieved with the use of powerful engineering tools like energy and exergy analysis to increase the performance of energy systems. Energy analysis is an old approach used to investigate various energy systems. The energy analysis concept has been criticized due to its weakness in measuring and evaluating the quality of energy. Exergy analysis has been found to be a most powerful tool due to its ability to measure the thermodynamics inefficiencies more precisely than the traditional energy analysis [1]. Demand for non-renewable energy resources have been increasing day by day and the current situation indicates that fossil fuel reserves will be not enough for the near future [6]. Therefore, utilization of renewable energy resources such as solar energy, wind energy, biomass is inevitable. Exergy is defined as maximum available work that can be extracted till system achieves dead state. In contrast to energy conservation (the First Law of Thermodynamics), exergy is not conserved during process (the Second Law of Thermodynamic).

Recently, the consumption of milk products has been increased worldwide due to an increased awareness about their nutritional value and beneficial effects on health. However, production of milk and milk products require a significant amount of energy. Interestingly, the dairy industry is fifth largest energy consuming industries after oil, chemical, pulp and paper mill, and iron and steel making industries [2].

II. CHALLENGES

Here are the challenges faced by energy saving practices, 1) more attention is given to production than innovation, 2) energy saving technologies needs major capital investments, 3) other priorities, 4) role of energy companies, 4) preference to proven old technologies over new risky technologies, and 5) short term financial horizons. Finally, a major disadvantage of energy analysis is that it does not truly indicate component efficiency because it is based on the 1st law of thermodynamics. The quality of energy has not been taken into account in performance calculations. Therefore energy efficiency analysis is misleading and not accurate.

III. MILK POWDER PRODUCTION SYSTEM

A schematic of milk powder production plant is shown in Figure 1. It involves several units like pasteurizer, evaporator, drier etc. Milk input from tankers is stored in large milk containers at ≈ 4^oC. The milk then goes to a cream separator which separate the cream (≈ 88 % fat) and skim milk (≈ 1.5 % fat) fractions using centrifugation. The skim milk is then sent to mixers where standardization of milk is done by adjusting its fat content. During pasteurization, skim milk is heated to 72^{o}C and held for 15 sec to destroy the pathogenic microorganisms. Then the milk is heated to a temperature of between 70 – 120^{o}C in the preheater before entering into the evaporator. In the evaporator, skim milk is concentrated to 45 % w/w total solids under vacuum at temperatures between 45 – 75^{o}C. The milk is atomized and sprayed in the large chamber. Hot air at a temperature of 190 – 240^{o}C comes in contact with this atomized milk and produces fine milk powder.

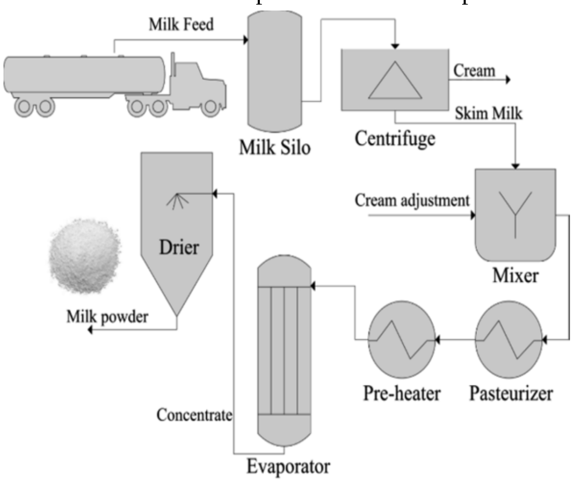

Fig. 1. Schematic of Milk powder manufacturing process

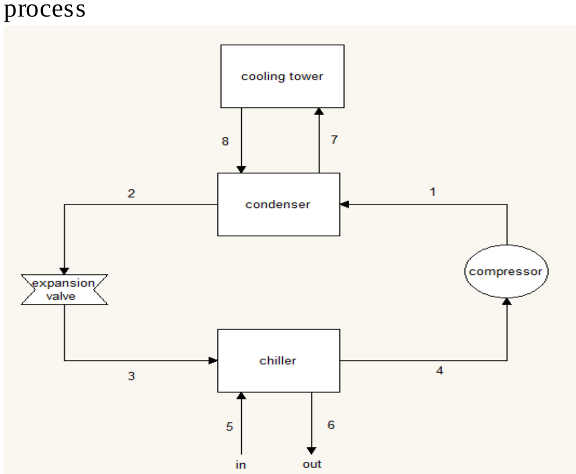

Fig. 2. Above-zero Refrigeration System

Figure 2 shows block diagram of above zero refrigeration system. It consists of compressor, condenser, expansion valve and chiller. A cooling tower is provided to lower the temperature of condenser water from 35^{0}C to 29^{0}C. The system uses ammonia as refrigerant. In chiller water is cooled to 2^{0}C which is further used to cool the milk. Figure 3 shows block diagram of milk pasteurisation system. It consists of three plate type heat exchanger. In heat exchanger 1 milk is heated to 75^{0}c using hot water and heat exchanger 2 milk is cooled down to 4^{0}c using ice water. In regenerative heat exchanger incoming stream of chilled milk is heated by outgoing stream of hot milk.

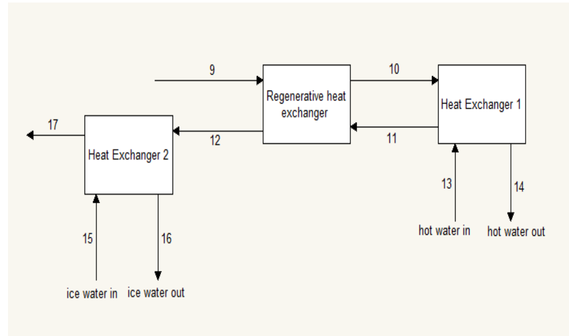

Fig. 3. Milk Pasteurization System

Nomenclature

Cp	specific heat (kJ/kg K)
ex	specific exergy (kJ/kg)
E	energy rate (kW)
Ex	exergy rate (kW)
h	specific enthalpy (kJ/kg)
m	mass flow rate (kg/s)
P	pressure (kPa)
Q	heat transfer rate (kW)
R	gas constant (kJ/kg K)
s	specific entropy (kJ/kg K)
T	temperature (K or ^{0}C)
W	rate of work or power (kW)
x	mass fraction
ε	exergy efficiency (%)

Subscripts

D	destruction
F	fuel
in	input
out	output
p	product
0	reference environment

IV. MATHEMATICAL MODELLING

The basic mass, energy and exergy balance equations are as following and exergy efficiency is calculated in which the system is at steady state

Mass balance equation:
$\sum m_{in} = \sum m_{out}$
Energy balance equation:
$Q + \sum m_{in} h_{in} = W + \sum m_{out} h_{out}$
Exergy balance equation:
$\sum Ex_{in} - \sum Ex_{out} = \sum Ex_D$
Exergy is given by:
$Ex = (h - h_0) - T_0(s - s_0)$
Where,
$(h - h_0) = c_p(T - T_0)$
$(s - s_0) = c_p \ln(T/T_0) - R \ln(P/P_0)$
Exergy efficiency:
$\varepsilon = (Ex_p) / (Ex_f)$
Specific heat capacity of milk:
$$c_p = 4.18x_w + 1.63x_{carb} + 2.05x_{fat} + 2.06x_{pro}$$

Tabel 1. Compositions of milk used for calculation of specific heat capacity

Component	Mass fraction in 3% fat standardized milk(Utsav)	Mass fraction in 0.1% fat skim milk
Water	0.891	0.917
Fat	0.030	0.001
Carbohydrate	0.046	0.048
Protein	0.033	0.034

V. EXERGY ANALYSIS

From the given equations exergy destruction rates and exergy efficiency of various system components is shown in figure 4. The cooler has the maximum exergy efficiency with 82.4% and the heater has the lowest exergy efficiency (9.7%). The evaporator has the highest (333.60 kW) exergy destruction rate among all components of the system.

Component #	Name	$\dot{Ex}_f$ (kW)	$\dot{Ex}_p$ (kW)	$\dot{Ex}_d$ (kW)	ε (%)
I	Evaporator	582.0	248.5	333.5	42.7
II	Feed pump	0.0	0.0	0.0	55.7
III	Spray drier	48.4	27.2	21.2	56.2
IV	Cooler	1.7	1.4	0.3	82.4
V	Economizer	8.8	6.9	2.0	77.7
VI	Fan	11.7	5.7	6.0	48.9
VII	Heater	66.7	6.5	60.2	9.7
VIII	Compressor	45.0	28.3	16.7	62.8
I-VIII		764.4	324.4	440.0	57.5

Fig.4 Exergy analysis of milk powder production system

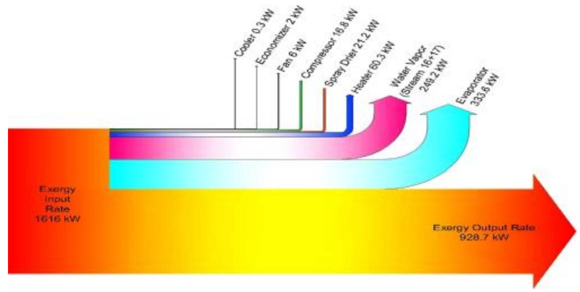

Fig. 5 Exergy flow diagram for milk powder production system

VI. CONCLUSION

Many research papers have been studied to understand and develop knowledge of milk powder production system.From above study we conclude that energy and exergy analysis tool is very useful and can be applied to milk powder production system in a dairy plant. We also reviewed that the evaporator consumes maximum energy and has highest exergy destruction rate. So the evaporator needs higher improvement in the system.

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