

Feasibility Analysis of Single Effect Vapour Absorption System in Dairy Industry

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Abstract-Today's world is facing two most important environmental problems. They are the energy crisis and the greenhouse effect. Scientists are working on how to eradicate these problems. Most of the today's innovations are based on this fact. Lithium-Bromide and water driven absorption refrigeration cycle is a burning example of this concept, which not only helps in minimizing the fossil fuel usage, hence the reduced CO₂ gas emission but also utilizes the low-grade heat from various industries and data centres. Energy, exergy and advanced exergy methods are used to analyse a milk powder production facility. In this study, feasibility analysis of single effect vapour absorption system in dairy industry has been evaluated.

Keywords- Feasibility, energy, single effect, dairy industry.

I. INTRODUCTION

Cooling and refrigeration demand constitutes a substantial fraction of global energy consumption. Since mechanical vapour compression systems require high-grade energy for their operation, alternative cooling systems such as absorption and adsorption cooling systems are receiving more attention than ever. Conventional cooling systems have greater overall working performance than absorption and adsorption cooling systems [1].

Today's world is facing two most important environmental problems. They are the energy crisis and the greenhouse effect. Scientists are working on how to eradicate these problems. Most of the today's innovations are based on this fact. Lithium-Bromide and water driven absorption refrigeration cycle is a burning example of this concept, which not only helps in minimizing the fossil fuel usage, hence the reduced CO₂ gas emission but also utilizes the low-grade heat from various industries and data centres. Energy, exergy and advanced exergy methods are used to analyse a milk powder production facility.

The production of dairy products, such as milk powder and cheese, is a major industrial sector in India and other countries. It is also one of the most energy-intensive industries within the food sector. India has a high share of agricultural products in their overall exports, of which 20% of the agricultural exports are dairy products.

Several scientific and engineering methods exist and are under continuous development, which target the determination, quantification and prioritisation of possible energy savings in complex and large-scale industrial processes. Dairy farming is one of the popular businesses these days. It is because of advancements in the dairy

industry. With the advancements, all the dairy works are done with the help of milk processing plants and dairy machines.

The vapour absorption refrigeration cycle or the absorption refrigerator is a closed loop cycle that uses low grade heat (waste heat) to provide cooling or refrigeration. It is different from the conventionally used vapour compression refrigerator in the sense that it works on chemical energy rather than electrical energy.

The absorption refrigerator uses a chemical substance as the absorbent which absorbs the refrigerant in the absorber and the waste heat is being used to recover the refrigerant free absorbent and enable it to be reused. (Ammonia + water) and (Lithium-bromide + water) are the two commercially used working pairs for this kind of refrigerators with their operability limitations.

In this work, simulation analysis and design of an absorption refrigeration system for milk processing plant using the LiBr + water working pair has been carried out, where water works as refrigerant and LiBr works as absorbent.

II. PAST STUDIES

Altunet al. (2020) investigated a solar-powered absorption cooling system modelled using the TRNSYS software.

The performance of the system using dynamic modelling under the weather conditions of Mugla, Trabzon, Izmir, Konya, Canakkale and Istanbul. The external catalog data file of the absorption chiller model was created to get more realistic results.

Jainet al. (2020) presented a novel structure of trans critical vapor compression-absorption integrated refrigeration system (TVCAIRS) based on its thermo-economic viability.

The integration of single effect vapor absorption refrigeration system (VARS) (with H₂O-LiBr fluid couple) in transcritical vapor compression refrigeration system (TVCRS) (with R744 refrigerant) provides a subcooling of 5 °C in the proposed configuration.

Merajet al. (2020) investigated performance analyses of interconnected N number of fully covered semi-transparent photovoltaic thermal integrated concentrator collectors combined with single effect vapor absorption refrigeration system. The proposed system was analysed under the constant mass flowrate of collectors' fluid. Mathematical expressions have also been derived for generator temperature of the absorption unit as a function of both design and operating parameters.

Jonathan et al. (2020) used a hydrophobic membrane desorber to separate water vapor from an aqueous LiBr solution. Influencing factors, such as the H₂O/LiBr solution and cooling water temperatures, were tested and analysed. With the experimental data, a solar collector system was simulated on a larger scale, considering a 1 m² membrane. The membrane desorber evaluation shows that the desorption rate of water vapor increased as the LiBr solution temperature increased and the cooling water temperature decreased. Based on the experimental data from the membrane desorber/condenser, a theoretical heat load was calculated to size a solar system.

Kanti et al. (2020) presented a comparative performance assessment of a single-effect and a double-effect vapor absorption system for the operation of a cold storage facility. The proposed cold storage is powered through a combination of a grid-interactive solar photovoltaic system and parabolic trough collectors.

A thermal model of the VAR systems is developed based on the first law and the second law of thermodynamics. An economic model has also been developed to compute the payback period.

Venkataramanet al. (2020) presented an up to date review of the heat driven absorption refrigeration/air conditioning systems specifically meant for transport applications. This is followed by a discussion on the major challenges involved in implementing such a technology for the transport sector, the ways in which such a technology can be developed further and why using heat driven refrigeration/air conditioning systems could be a game changer in the automotive industry.

Alhamidet al. (2020) presented a solar-gas fired absorption cooling installed and tested in a real

environment at the University of Indonesia, Depok, Indonesia. The cooling system provides chilled water to the building of the Mechanical Research Center of the university. This system has a unique single/double-effect water/Lithium Bromide absorption chiller with a nominal cooling capacity of 239 kW.

In addition, the system consists of evacuated tube solar collectors (~181 m² total aperture area) and fan coil units installed in the building.

Liuet al. (2020) presented a LiBr/H₂O absorption chiller and a Kalina integrated in cascade to achieve full utilization of low-grade waste heat. A parametric analysis has been conducted to investigate the effect of key operational parameters in terms of turbine-inlet pressure, turbine-outlet pressure, ammonia concentration, segment temperature and refrigeration temperature.

The coupled system is then compared with the Kalina cycle without absorption chiller, in terms of the turbine-outlet pressure and the net power output.

III. OBJECTIVES OF STUDY

The prime objectives of the study are;

- To study the system of a milk pasteurization process assisted by VAR milk processing plant by thermodynamic modelling.
- To develop an EES code using computer simulation program for simulating the cycle.
- To study the effect of exit temperature of generator, condenser and evaporator of single effect vapour absorption system on COP, and heat load of the system.

IV. THERMODYNAMIC MODELLING

An increase in energy efficiency of the industrial sector would significantly reduce the greenhouse gas emissions caused by the burning of fossil fuels and the production costs associated with energy use. The production of dairy products, such as milk powder and cheese, is a major industrial sector in India. It is also one of the most energy-intensive industries within the food sector [1].

The aim of the present work was to identify this efficiency potential by applying and assessing thermodynamic method based on energy analysis industry in particular, several studies were conducted in the 40 last years. These studies primarily analysed the milk processing or focused on the drying process [8]. Figure below Illustrates a schematic diagram of the considered system of a milk pasteurization process assisted by VAR. This system was adopted from a study performed by Kiruja [13].

The whole energy requirement of the pasteurization system was supplied from Single Stage LiBr VAR was used for both heating and cooling purposes.

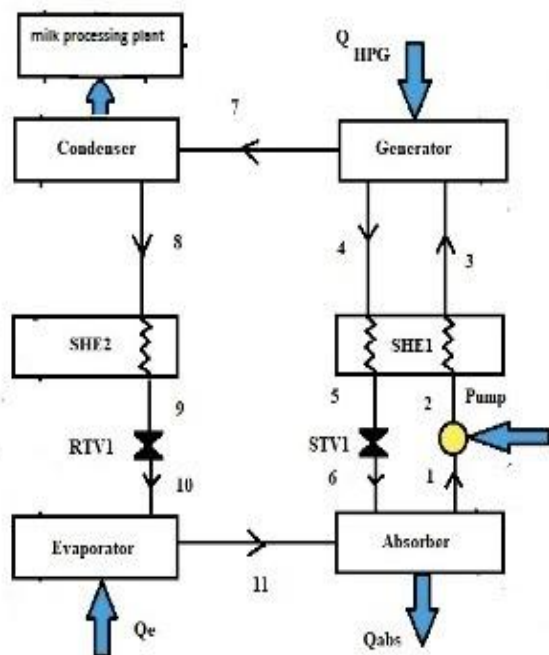


Fig 1. Schematic diagram of single effect VAR with milk processing plant.

The process modeling built upon the real operation parameters and conditions of the production line, as found in process data and from on-site measurements.

The following assumptions were taken. The processing line produces different products that are pasteurized at different temperature levels, and they have varying dry matter contents after the mixing unit, depending on the milk additives. The input feed was modeled as a representative mixture with a composition corresponding to the use of skimmed milk and additives.

In this work the most common set-up was chosen. It consists of a single-effect VAR. The heat losses from process components, such as heat exchanger, were neglected. The start-up behaviour of the production lines and cleaning in place (CIP) were not included in this work. The reader is referred to [31], where a detailed technical description of the technologies, components and processes used in the production of milk powder is presented.

The work by [32] gives an extensive description of the evaporation with vapour compression in single and multiple stages for salt water desalination. The incoming raw milk is heated to the separation temperature at 50 °C, where the raw milk is separated into cream and skimmed milk by means of a centrifuge. The skimmed milk and cream are then pasteurised and cooled down. The resulting mixture is pasteurised and cooled down a second time. The heat exchangers were modelled with energy balances, based on the streams inlet and outlet enthalpies and mass

flow rates. The refrigeration unit was based on a simple vapour compression cycle using LiBr as a refrigerant.

V. RESULT AND DISCUSSION

An energetic analysis of LiBr-H₂O absorption system for milk processing plant is done in this current study. First law of thermodynamics has been used for performing analysis. Further, an EES code has been developed using computer simulation program for simulating the cycle and validation of results with experimental one.

The analysis of the results generally aims at finding inefficiencies or improvement potentials in the system and to find them in minimum demands, meaning the minimum in externally supplied heat and cooling.

The effect of exit temperature of generator, condenser and evaporator on COP, and heat load, has been analysed. The operating parameters are selected as generator temperature (75°C), absorber temperature (30°C), condenser temperature (30°C) and evaporator temperature (5°).

1. Effect of Generator Temperature:

In this section the effect of generator temperature on heat flow rate in condenser (Q_c), and COP of absorption system has been discussed.

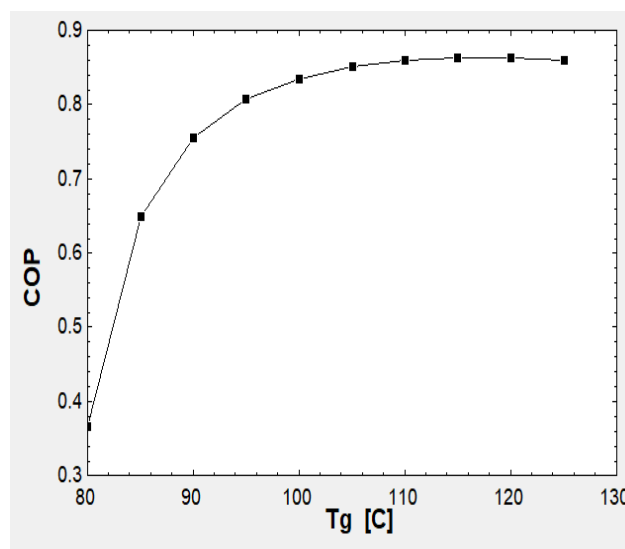


Fig 2. Effect of generator exit temperature on s COP.

Fig. 1. shows the effect of generator exit temperature on the COP, with increase in generator exit temperature the COP of the system is increasing. It is due to fact that circulation ratio decreases. COP value is highest at temperature 115°C i.e. 0.8623. Modi et.al. (2017) observed the same trend of the COP with respect to generator exit temperature.

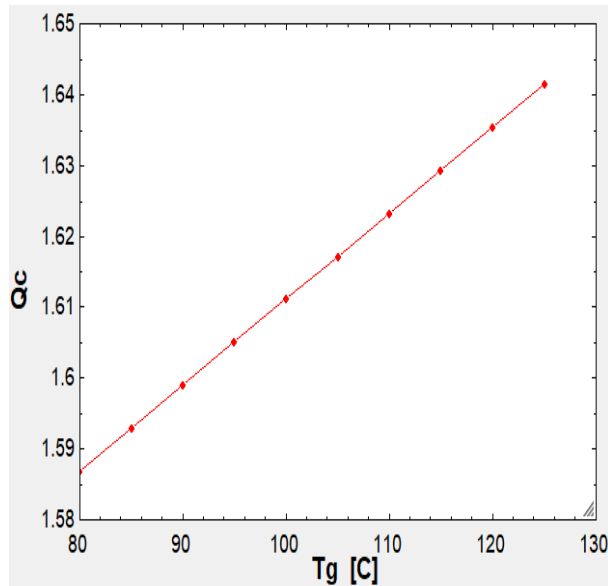


Fig 3. Effect of generator exit temperature on component's heat load.

Fig. 2. shows the effect of generator exit temperature on the heat released in condenser, with increase in generator exit temperature the condenser heat load increases gradually.

2. Effect of Evaporator Temperature:

In this section the effect of evaporator temperature on heat flow rate in condenser (Q_c), and COP of absorption system has been discussed.

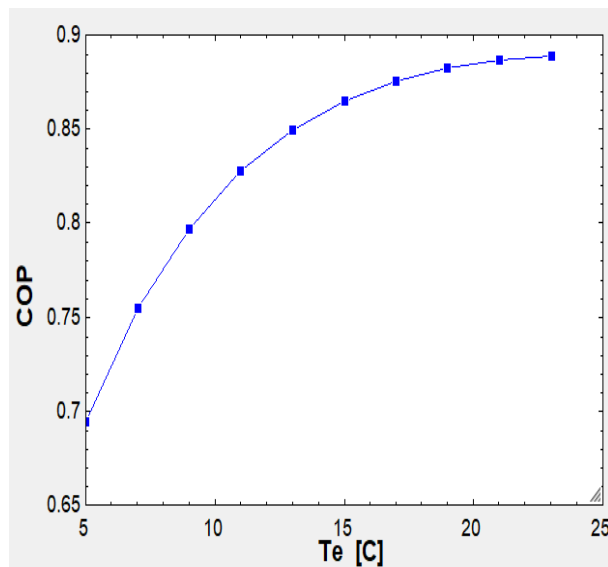


Fig 4. Effect of evaporator exit temperature on COP.

3. Effect of Condenser Temperature:

In this section the effect of condenser temperature on heat flow rate in condenser (Q_c), and COP of absorption system has been discussed.

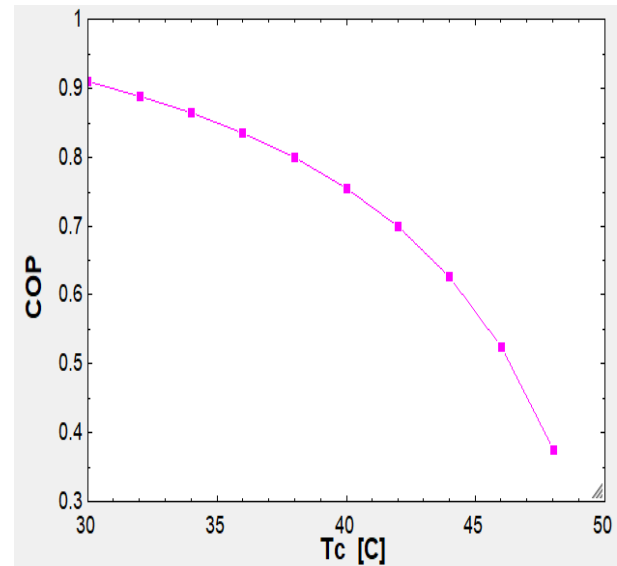


Fig 5. Effect of condenser exit temperature on COP.

The above figure shows the effect of condenser exit temperature on the COP, with increase in condenser exit temperature the COP of the system decreases gradually.

VI. CONCLUSION

In the proposed work, a milk powder production system running with the help of single effect VAR of capacity 1.5 kW is presented. The aim of the work was to analyse the feasibility of system. The energy analysis, focusing on the main components, was the first step in defining the system. Thermal (the first law) analysis is mostly used to evaluate the performance of various thermal systems. In this regard, we have carried out energy analyses of a milk pasteurization process assisted by single effect vapour absorption system using the operational data taken from the literature.

The concluding remarks of the present study can be summarized as follows:

- It was found in the study that COP increases with increasing the generator exit temperature and evaporator exit temperature while it is decreasing with increasing condenser exit temperature.
- With increase in condenser exit temperature the condenser heat load decreases gradually.
- With increase in generator exit temperature the condenser heat load increases gradually.
- According to study conducted by Yildrem and Genc(2015) the heat required in dairy industry for process heat application is 2375 kW but in this current work the heat reject in condenser is of same order approx. therefore single effect absorption system is feasible in process heat application in dairy industry.

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