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THERMAL PERFORMANCE ANALYSIS OF SINGLE EFFECT VAPOUR ABSORPTION SYSTEM

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1. INTRODUCTION

Cooling and refrigeration demand accounts for a significant portion of global energy consumption. Alternative cooling systems, including absorption and adsorption cooling systems, received more attention than before because mechanical vapour compression systems demand high-grade energy to operate. Conventional cooling methods outperform absorption and adsorption cooling systems it terms of overall performance [1].

Today's world is confronted with two major environmental issues. The energy problem and the greenhouse impact are indeed the two issues at hand. Scientists were attempting to find a solution to this issue. That fact underpins the majority of today's inventions. The lithium-bromide and water-driven absorption refrigeration cycle is indeed an excellent illustration of just this idea since it often reduces fossil fuel use and hence CO2 emissions. Still, it also makes use of the low-grade heat of various businesses and data centers.

A milk powder production facility is investigated using energy, exergy, and advanced exergy technologies. In India and other nations, dairy products like milk powder or cheese are just a big industry. Within in the food industry, it has become one of the most energy-intensive. India's agricultural exports account for a large portion of a country's total exports, with dairy products accounting for 20% of all agricultural exports. Many scientific and engineering approaches for determining, quantifying, and prioritizing potential energy savings in complicated and large-scale industrial processes exist and are constantly being developed. Nowadays, dairy farming is among the most popular industries. It's due to technological improvements in the dairy sector. All dairy labour is now accomplished with the help of milk processing plants and dairy equipment, thanks to technical developments.

The absorption refrigerator, also known as the vapour absorption refrigeration cycle, is a closed-loop system that provides cooling or refrigeration by using low-grade heat (waste heat). It differs from traditional vapour compression refrigerators in that it uses chemical energy instead of electrical power to operate. The absorbent in such an absorption refrigerator is a chemical material that absorbs the refrigerant in the absorber, and waste heat is utilized to recover the refrigerant-free absorbent from recycling it. (Ammonia + water) and (Lithium-bromide + water) are the two most often used commercial working pairs for this type of refrigerator, each with its own set of restrictions.

The simulated study and design of such an absorption refrigeration system for a milk processing factory utilizing the LiBr + water working pair, where water acts as both a refrigerant and LiBr acts as an absorbent, was carried out in every project.

2. TAGUCHI METHOD

Genichi Taguchi created the Taguchi approach as a statistical method for enhancing product performance and quality. The important objective right before analysis, according to Taguchi, is really to set up the experiment. It is only through that method that the process' quality may be improved. This approach was able to reach the final output value while minimizing the variability across the output value at the lowest possible cost. He thought that the most straightforward approach to improve quality would have been to design and build it into the product. The major goal of this approach is to provide a high-quality product at a low cost to the producer. Taguchi devised a method for examining how various parameters impact the mean and variance of a process performance characteristic through experiment design. Taguchi's latest design entails using orthogonal arrays to enhance the number of recommendations influencing the technique, and also the amount where they've been varied. Rather than evaluating all potential combinations like the factorial layout, the Taguchi method evaluates a variety of combinations. The following should help discover whether factors virtually do have an influence on product quality with the least amount of experimenting, saving you time and money. Taguchi arrays are often created or investigated. By hand, smaller arrays are frequently slow; large arrays could be used to implement deterministic algorithms. Arrays may usually be found on the internet. The number of recommendations (variables) plus the number of ranges have been used to determine the arrays (levels).

Design Of Experiment

The Taguchi method's overall steps are described:

- Determine which machining parameters, including such spindle speed, feed rate, and tool profile, will be influenced with FSW factors. The potential of a technique might also be a minimum or maximum value, such as increasing the hardness value.
- Define the strategic variables that influence the machining process. Variables are strategy factors that impact performance measurements such as cutting speed, feed rate, and other metrics that could be easily changed. It is necessary to provide the number of levels at which the variables should

indeed be changed. A feed rate, for example, could be adjusted between a low as well as a high value.

- Create orthogonal arrays again for variables design, stating how many and in what conditions each experiment will be conducted. Orthogonal arrays are chosen based on the number of variables as well as the amounts of variation for every parameter, that will be explored more below.
- Carry out the experiments listed in the finished array to obtain information on the impact just on performance metric.
- Total data analysis to determine the impact of various variables upon that performance measure.

Process Parameters Design Orthogonal Array

The orthogonal array experimental design introduced by Taguchi can be used to investigate the after-effect of a number of factors on a performance characteristic in such a condensed set of tests. Following the determination of the factors impacting a manageable process, precise levels where these variables should be modified must undoubtedly be defined. Determining which degrees of parameters to use necessitates a full understanding of the process, including the parameter's lowest, maximum, and most recent values. If a gap between a parameter's minimum and maximum value seems considerable, the values being tested might be spaced further apart, or additional values could've been tried. If indeed the number of parameters is low, fewer values can be tested, or the values that are tested can be grouped together. When choosing how many degrees of such a parameter to include in the experimental design, the cost of performing the experiments must be taken into account. To aid with in selection of a proper orthogonal array, the quantity of levels for various parameters with in experimental design are usually set to be of the same. The right orthogonal array could've been selected if the number of parameters and levels were known. The name of both the proper array may be found using the array selector table below thinking the about column and row in terms of number of variables and levels. When you've identified the title, you may move on to the next step (the subscript presents the amount of studies that must certainly be completed), It is possible to look up the specified array. There seem to be hyperlinks to many of the predefined arrays with in array selection table. Those arrays are created using a Taguchi algorithm that produces each variable and location to just be tested equally.

Table 1 Array Selectors

		NUMBER OF PARAMETERS (P)													
		2	3	4	5	6	7	8	9	10	11	12	13	14	15
NO OF LEVELS	2	L_4	L_4	L_8	L_8	L_8	L_8	L_{12}	L_{12}	L_{12}	L_{12}	L_{16}	L_{16}	L_{16}	L_{16}
	3	L_9	L_9	L_9	L_{18}	L_{18}	L_{18}	L_{18}	L_{27}	L_{27}	L_{27}	L_{27}	L_{27}	L_{36}	L_{36}
	4	L_{16}	L_{16}	L_{16}	L_{16}	L_{32}	L_{32}	L_{32}	L_{32}	L_{32}					
	5	L_{25}	L_{25}	L_{25}	L_{25}	L_{25}	L_{50}	L_{50}	L_{50}	L_{50}	L_{50}	L_{50}			

The parameter in the array selection is assumed to have the same number of levels. That isn't always the case. In most cases, the greatest value is utilised, or the excess is divided.

Analyzing Experiment Data

The measured performance quality out of each trial may be utilised to assess the overall efficacy of the various parameters once the experimental design has been developed and the tests have been moved out. The following L9 array will be used to demonstrate the information inspection method, although the ideas may be applied to just about any type of array. It is seen in this array that a variety of repeated observations (trials) are possible. Tij denotes the various trials, where I denote the experiment number and j denotes the trial number. The signal-to-noise ratio, or SN number, must always be computed for each experiment to determine the influence every variable will have on the result.

3. Thermodynamic Modelling

An improvement in industrial fuel efficiency will dramatically reduce greenhouse gas emissions generated by the burning of fossil fuels, and also the costs of manufacturing connected to energy consumption. In India, the manufacture of dairy products such as milk powder and cheese is a big industry. This is also one of the food industry's most energy-intensive sectors [1]. The goal of this study would be to find and evaluate such efficiency potential using a thermodynamic technique based on energy analysis. Many researches have been undertaken in the last 40 years in business in particular. That research mainly looked at the milk processing or the drying process [8]. The schematic figure below depicts the suggested system of a VAR-assisted milk pasteurisation process. The system was developed based on Kiruja's research [13]. The pasteurisation system's whole energy need was met by Single Stage LiBr VAR, which was utilised both for heating and cooling.

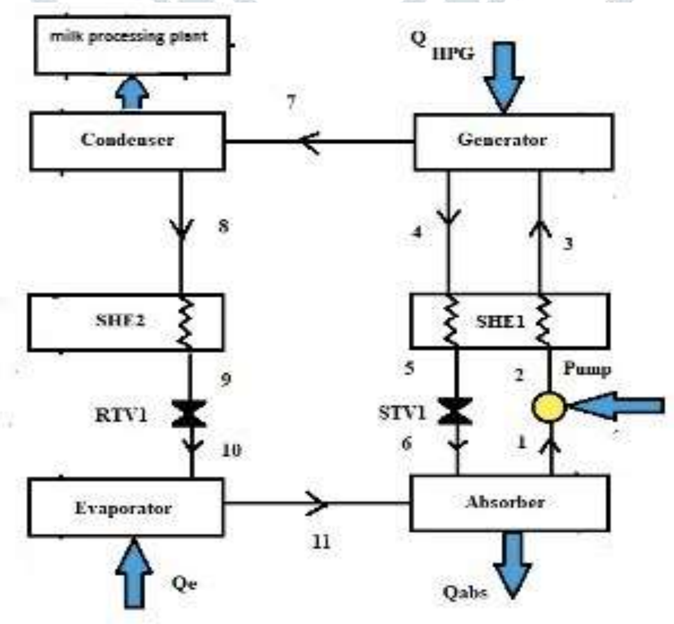

Fig. 1: Schematic diagram of single effect VAR with milk processing plant

This top - down models was based on the actual production line operation characteristics and circumstances as found in process data and on-site measurements. They made the following assumptions.

Depending here on milk additions, the processing line generates distinct products that are pasteurised at different temperatures and also have varied dry matter contents following the mixing unit. The input feed is modelled as a presentative combination with a composition that matched the usage of skimmed milk and other additions. A most frequent set-up is chosen for this project. It really is made up of a VAR with a single effect. Heat losses from process components including the heat exchanger also weren't taken into account. This work doesn't really address the start-up behaviour of both the production lines or cleaning in place (CIP). The reader is directed to [31], which has a comprehensive technical explanation of the technologies, components, and procedures involved in manufacturing of milk powder. [32] Describes the evaporation and vapour compression in single and multiple phases for salt water desalination in great detail. The incoming raw mixture was heated toward the separation temperature of 50°C, and then centrifuged to separate the raw milk to cream and skimmed milk. After that, the skimmed milk & cream are pasteurised then chilled. The resultant mixture is pasteurised and then chilled again. Energy balances have been used to model these heat exchangers, which were based here on streams' intake and output enthalpies and mass flow rates. The refrigeration system used LiBr as a refrigerant and also was based on such a basic vapour compression cycle.

Assumptions

(a) All processes are now in a steady state continuous flowing, with no potential or kinetic energy impacts.

(a) With respective particular pressures and temperatures, ammonia water solutions are considered to have been in equilibrium in the generator and absorber.

(c) Heat transfer into the system and work transfer out the system are both positive.

(d) “Pressure and heat losses in pipelines and system components (generator, condenser, evaporator, absorber, regenerator, pasteurizer cooler, etc.) are not taken into account.”

(e) The throttle valves work in such an adiabatic state, resulting in minimal enthalpy process.

(h) The milk's cold storage temperature is set at 4 °C.

(I) The heat exchanger inside the VAC is considered to have an efficiency of 0.80.

(j) The regenerator's efficiency was estimated to be 0.95.

(l) The milk's pasteurisation temperature is maintained at 76°C..

(m) The temperatures of the condenser, evaporator, the absorber were assumed to be 35°C, 5°C, and 35°C, respectively.

(n) The geothermal resource pressure was considered to be the same as the generator pressure.

(o) The chilled water pressure being considered to be the same as atmospheric pressure.

(p) The reference environment's temperature and pressure were set to 25°C and 101.325 kPa, respectively.

This means that the power balance under stable state may well be represented as follows on a rate form:

Mass Conservation

This involves mass balance of total mass so each material of both the solution. The governing equations of mass the type of material conservation for the a steady state-flow system are:

$$\sum m_i - \sum m_o = 0$$

$$\sum m_i X_i - \sum m_o X_o = 0$$

Where, m is the mass flow rate and X is the mass fraction of LiBr in the solution.

First Law Analysis

At each component of both the absorption system, a first law of thermodynamics is as follows:

$$\sum \dot{Q} - \sum \dot{W} = \sum m_0 h_0 - \sum m_i h_i$$

Using eq. the mass and energy balance of each components of absorption system are developed as follows:

Generator:

$$\dot{Q}_{gen} = \dot{m}_{20}(h_{19} - h_{20})$$
$$\dot{Q}_{gen} = \dot{m}_1 h_1 + \dot{m}_8 h_8 - \dot{m}_7 h_7$$

RHE:

$$\dot{m}_6 = \dot{m}_7, \dot{m}_8 = \dot{m}_9$$
$$\dot{m}_6 h_6 + \dot{m}_8 h_8 = \dot{m}_7 h_7 + \dot{m}_9 h_9$$

Evaporator:

$$\dot{m}_3 = \dot{m}_4$$
$$\dot{Q}_{eva} = \dot{m}_3(h_4 - h_3)$$

Absorber:

$$\dot{m}_5 = \dot{m}_4 + \dot{m}_{10}$$
$$\dot{Q}_{abs} = \dot{m}_4 h_4 + \dot{m}_{10} h_{10} - \dot{m}_5 h_5$$

Pump:

$$\dot{m}_5 = \dot{m}_6$$
$$\dot{W}_{pump} = \dot{m}_5(h_6 - h_5)$$

Pasteuriser:

$$\dot{Q}_{past} = \dot{m}_{12}Cp_{milk}(T_{13} - T_{12})$$
$$\dot{Q}_{past} = \dot{m}_{17}(h_{17} - h_{18})$$

Condenser:

$$\dot{m}_1 = \dot{m}_2$$
$$\dot{Q}_{con} = \dot{m}_1(h_1 - h_2)$$

SHE:

The overall performance of absorption system is determined by evaluating its coefficient of performance (COP):

$$COP = \frac{Q_e}{Q_{HTG} + W_p}$$

where, Qe is the refrigerant effect, Q_G is the heat rate in generator and W_p is the pump work.

The operating temperatures chosen are as follows-

1. Generator Temperature, Tg =75°C

2. Condenser Temperature, Tc= 35°C

3. Absorber Temperature, Ta =35°C

4. Evaporator Temperature, Te =5°C

4. Result and Discussion

This research looks at the energy usage of a LiBr-H20 absorption system in a milk processing factory. The investigation was conducted using the first rule of thermodynamics. Additionally, an EES code was created using a computer simulation tool for modelling the cycle and comparing the findings to the experimental data. The goal of a results analysis is really to uncover inefficiencies or process improvements in the system, as well as to determine the minimal needs, or the lowest amount of heat or cooling that can be provided outside. The influence of generator, condenser, and evaporator exit temperatures on COP and heat load has been studied and confirmed, and is covered in sections 5.1, 5.2, 5.3, and 5.4. Generator temperature (75°C), absorber temperature (30°C), condenser temperature (30°C), and evaporator temperature (5°) are the working parameters.

Parameter And Their Levels

Taguchi methods, developed the Genichi Taguchi, are statistical approaches, sometimes known as resilient design methods, that are used to enhance several elements for a certain objective function. It must have been originally solely used in engineering studies, but it can now be used in engineering, biotechnology, marketing, and advertising, among other fields. The generator temperature, evaporator temperature, condenser temperature, & absorber temperature are all taken into account in the analysis to optimise the absorption refrigeration system. Table 5.2 shows the parameter levels that were determined based on a literature review. With such a lower number more experimental runs, the Taguchi approach optimises system performance. Taguchi method's key advantages include reduced time, cost, and effort. Taguchi technique includes an orthogonal array table for choosing the number of experimental runs for complete factorial analysis. In just this study, an orthogonal array of L9 is selected and created based on selected characteristics and levels, as indicated in Table 2.

Table 2: Parameters and their levels

Sr. No.	Input parameters	Level 1	Level 2	Level 3
1	Generator temperature, T_g	95 °C	120 °C	140 °C
2	Condenser temperature, T_c	25 °C	40 °C	60 °C
3	Absorber temperature, T_a	20 °C	30 °C	50 °C
4	Evaporator temperature, T_e	6 °C	14 °C	24 °C

The Taguchi technique is used in the same work to enhance COP and heat recovery in such a dairy condenser. The outcomes of the goal function, such as COP and heat recovery within condenser, are transformed to the S/N ratio in the first stage. Because both COP and heat recovery within condenser are required to just be maximized in the this study, more higher the better features are chosen.

The S/N ratio for higher the better is calculated using Eq. (23):

$$S/N = -10\text{Log}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^2}\right) \qquad (23)$$

Where, n indicates the number of case and y_i describes the result value for the *i*th performance characteristics.

Simulation Results

The Taguchi method was used for the first phase to determine the impact of process parameters on the COP. In just this case, the COP is computed by modelling the cycle using EES software and the thermodynamic model. As indicated in Table 5.4, there are indeed a total of 9 examples with varying levels of parameters. Tg = 95 °C, Tc = 25 °C, Ta = 20 °C, and Te = 6 °C, for example, are the COP and heat recovery inside a condenser. In the following scenarios, the COP and heat recovery in the condenser was computed using various combinations of Tg, Tc, Ta, and Te, with the results displayed in Table 3. Following that, a S/N ratio related to COP and heat recovery in the condenser was determined, including a rank table, as seen in the Table 3.

Table 3: Parameters and their levels

Case	Parameters (°C)				COP
	T_g	T_c	T_a	T_e	
1	95	25	20	6	0.9088
2	95	40	30	14	0.8722
3	95	60	50	24	0.5126
4	120	25	30	24	0.8576
5	120	40	50	6	0.8309
6	120	60	20	14	0.7894
7	140	25	50	14	0.8690
8	140	40	20	24	0.8121
9	140	60	30	6	0.7773

System Optimization Using Taguchi Method

The Taguchi approach often uses intuitive analysis to investigate factorial effects and contribution ratios of each control element on the aim. Table 5.5 shows factorial effects on SNR-COP based on the raw data in Table 5.1 and the above-mentioned calculation algorithms. In intuitive analysis, the average SNR, which indicates the level's output response, should first be computed. The arithmetic mean value of SNRs for every level of the each factor is referred to as the average SNR.

Table 4: Factorial effects for SNR-COP

Level	Tg	Tc	Ta	Te
1	-2.608	-1.128	-1.564	-1.543
2	-1.666	-1.535	-1.570	-1.487
3	-1.739	-3.349	-2.878	-2.982
Delta	0.942	2.221	1.314	1.495
Rank	4	1	3	2

Above table indicates that, Tc has more effect on COP of system than other variables.

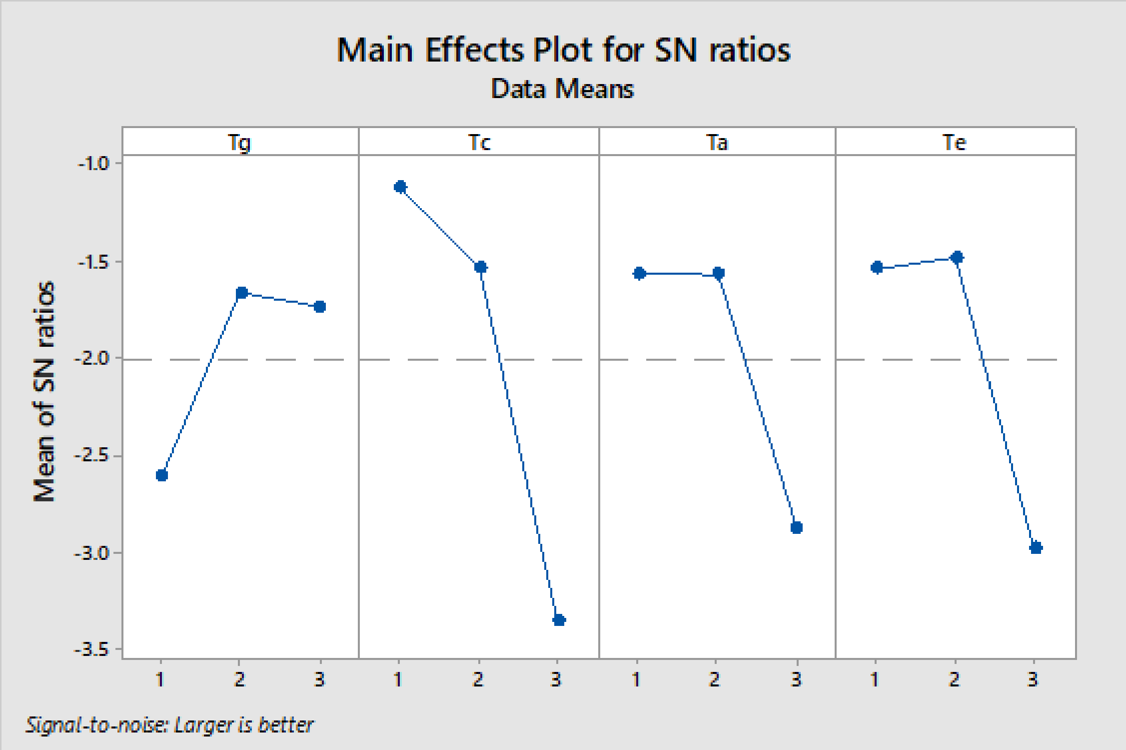

Fig. 2: Main-effect plots for SNR- COP

This has long been assumed that the factor's ideal level is the one with the highest SNR. If interaction effects between all components are insignificant, the level combinations with the highest SNR-COP for each element are considered the best level combination for COP. The best combination for SNR-COP is A2B1C2D2, as shown in Fig. 2. The simulation has been done with this combination, and the maximum COP is 0.8844.

5. CONCLUSION

A milk powder manufacturing system with such a single loop VAR of 1.5 kW capacity is proposed. The goal of this work was to look into the viability of employing Taguchi approach to optimise a system. The energy analysis was the initial stage in designing the system, with a focus here on primary components. The first rule of thermodynamics is commonly used to assess the contribution of different thermal systems. In just this context, they used operational data from of the literature to conduct energy evaluations of a milk pasteurisation process supported by a single effect vapour absorption system. This following is a summary of the current study's final remarks:

1. The study discovered that raising the generator exit temperature and evaporator exit temperature enhances COP, but increasing the condenser exit temperature decreases it.
2. The condenser heat load steadily reduces as the condenser exit temperature rises.
3. As the generator exit temperature rises, the condenser heat load rises as well.
4. As per a study conducted by Yildrem and Genc (2015), this same temperature required with in dairy industry for process heat application would be 2375 kW, but the heat reject inside the

condenser in this current work to be of the same order approx., so a single effect absorption system inside the dairy industry is feasible.

5. The best SNR-COP combination was determined to be A2B1C2D2. The simulation was done with this combination, and the maximum COP is 0.8844.
6. According to the rank table, Tc seems to have a greater impact on the system's COP than the other factors.

FUTURE SCOPE

India has been one of the world's fastest growing dairy nations. Demand for dairy and food items is growing step by step as even the population grows and people's lifestyles improve. Despite rising product demand, energy demand, as well as commercial energy consumption, has risen by 6% over the previous two decades, putting India in fifth place on the planet. Industry consumes 49 percent of total energy. Coal import reliance is now 9%, crude oil and petroleum product import dependency is 77 percent, and natural gas import dependency is 31 percent. 2010 (Desai and Zala) Today, the majority of energy is generated in central power plants that use coal, oil, water, gas, or fossil nuclear materials as primary fuels. They are not renewable, restricted in terms of regeneration (everyone on the planet has a limit), less efficient (65-75 percent), and costly. It is necessary to conduct more study to better understand the resource, component, and system factors in order to employ the technology in a cost-effective manner.

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