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Optimization Energy Consumption Using Constrains Temperature and Fan Speed on Salt Dryer Machine Based on Taguchi L9 Statistics Model

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ABSTRACT

Madura island meet mostly of the salt demand in Indonesia, Sampang, Pamekasan, and Sumenep are three of the four districts of the island that produce salt. Salt ponds run on traditional way over generations, this situation is highly dependent on sunlight in the salt drying process. This research aims to find the optimal parameters on the salt drying machine on the efficiency of energy consumption on the machine. Optimization using Taguchi orthogonal array L9. General linear ANOVA used to define contribution level of each parameter. Fan speed parameter has 3 levels namely; low, medium, and high. Drying temperature has 3 levels they are; 18℃, 20℃ and 22℃. Quality control term on this research is smaller better, the less energy consumption during drying process leads to efficiency cost for dryer machine operation. The lowest energy consumption found on this research is 4687 kWh, achieved on temperature 20℃ and low fan speed. The highest energy consumption found on research is 5492 kWh, achieved on temperature 20℃ and low fan speed. Based on Taguchi L9 recommendation optimum combination is fan speed low, 20℃ on drying temperature. Parameter drying temperature is dominant compared to parameter fan speed. Parameter fan speed has contribution 0.64% and parameter dryer temperature process has contribution 94.7%.

1. INTRODUCTION

Madura Island, situated in Indonesia, holds a significant role in the country's salt production landscape [1]. The island's coastal areas provide an ideal environment for salt extraction, with its shallow, sun-soaked salt pans and access to seawater [2]. The process of salt production on Madura Island involves a harmonious blend of traditional and modern methods [3, 4]. Long-standing local populations have engaged in salt farming, making use of the island's considerable natural resources [5]. An array of shallow ponds utilized to carefully channel seawater, which then evaporates under the hot sun in controlled way. Salt crystals begin form when the water gradually evaporates and begin accumulating upwards [6]. The crystals are carefully raked and collected by workers, who subsequently wash, purify, and make them ready for use. This long-standing custom not only supports the island's economy but also serves as a showcase for Madura Island's rich cultural history of salt production [7, 8].

The salt drying process in salt ponds in Madura has so far used traditional methods. The traditional salt drying process in Madura has both advantages and disadvantages. One of its key advantages is its low cost, as it relies on natural resources like sunlight and wind, making it accessible and sustainable for local communities [9]. This method also preserves cultural heritage and supports small-scale salt farmers. However, the disadvantages include its reliance on weather conditions, which can lead to inconsistent production and longer drying times The process is also labour-intensive and less efficient compared to modern techniques, leading to lower yields and higher risks of contamination from environmental factors [10].

Seawater is drawn through a primary tunnel and pumped to an elevation of 1.5 meters using a windmill, ensuring it remains filled during high tide. In a crystallization pond (200 m² in size), the seawater is left to settle for 7 to 10 days until it crystallizes. The salt crystals, which form beneath the bittern solution, can then be scraped off and collected at a designated collection point [11]. Madura island region has a tendency to have a dry climate. The rain intensity is only 16.1% and only has 31 rain stations. Only 5 of them are independent. This indicates that there is no change in rain data between periods in general in the Madura region. However, the maximum daily extreme rainfall trend change is 12.9% of daily extreme rainfall data [12]. For salt farmers, this is a loss, especially if the salt has entered the bitter solution and the age of harvest is ready. Madura Island is a major supplier of salt to Indonesia, some of which is exported [13]. The incorporation of salt dryer machines has come to be recognized as a beneficial innovation in an effort to increase the productivity and effectiveness of conventional salt drying processes on Madura Island. These devices expertly combine cutting-edge technology with the knowledge of time-tested procedures. Salt dryer machines use regulated heat and airflow to quicken the crystallization of salt from seawater [14].

One of the primary challenges lies in its dependence on natural factors, such as weather conditions and the availability of sunlight. Rainy seasons and overcast days can disrupt the evaporation process, leading to reduced yields and prolonged production timelines [15]. Additionally, the labour-intensive nature of traditional methods requires a considerable workforce, which can be impacted by changing demographics and migration patterns [16]. Moreover, the increasing demand for salt necessitates higher production rates, which the traditional methods might struggle to meet. Balancing the preservation of cultural heritage with the need for efficiency and scalability poses a complex dilemma [17]. As Madura Island navigates these constraints, it showcases its resilience by exploring innovative solutions that respect its traditions while embracing modern practices to ensure a sustainable and thriving salt industry [18].

The application Statistics of Taguchi optimization principles to salt dryer machine parameters represents a strategic leap in enhancing the efficiency and effectiveness of the salt production process on Madura Island. By systematically varying and analysing variables such as temperature and fan speed during drying process. Taguchi method enables a systematic exploration of the optimal combination of parameters that low energy consumption during this machine operation. This approach empowers salt producers to not only streamline production but also minimize energy consumption and resource wastage.

The optimization of energy usage in a salt drier machine includes thoughtful assessment of the significant influences of temperature and fan speed. An analysis of variance (ANOVA) was performed to assess the impact of these factors on energy efficiency. The individual and interactive impacts of temperature and fan speed on energy consumption were assessed by considering them as independent variables [19]. The findings demonstrated notable correlations between temperature and fan speed, indicating that achieving simultaneous optimization of both parameters could result in a decrease in energy use. The ANOVA analysis also facilitated the identification of the most favourable operating parameters that reduce energy consumption while preserving the quality of the drying process [20]. This methodology offers a structured technique to optimize the performance of the machine, guaranteeing energy efficiency while considering the imposed operational limitations [21].

To maximize the performance of a drier machine by reducing energy consumption and improving drying efficiency, the Taguchi approach, a robust design technique, was utilized [22, 23]. This technique entails the methodical manipulation of crucial operating parameters such as temperature, and fan speed in order to determine their most favourable values. Employing an orthogonal array, this approach effectively assesses the impact of these parameters on the performance of the machine with few experimental iterations. In order to enhance process consistency, the Taguchi approach evaluates the signal-to-noise ratio to guarantee optimal operation of the dryer machine under different working situations [24]. The use of this approach enabled the identification of ideal parameters, resulting in a reduction in energy consumption and an improvement in the overall quality of the drying process. Consequently, this presents a cost-effective solution for industrial applications.

2. METHODS

2.1 Construction of salt drying machine

The design and construction of the salt drying machine involved several stages. First, the frame of the machine was fabricated using S37 steel, chosen for its strength and durability. Hollow iron in two sizes was used: 4×4 cm with a 1 mm thickness for the main structure, and 4×2 cm with a 1 mm thickness for the section where the salt would be placed for drying. The steel components were joined using a welding machine, with welding parameters set at a current of 150 A and a voltage of 22 V. The welding process utilized ER70S-6 welding wire in the 1F (flat) position to ensure strong and stable joints. These parameters align with established guidelines for welding low-carbon steel, which recommend using moderate currents and voltages to balance penetration and minimize spatter [25]. After the frame was completed, plywood was cut to size using a cutting machine and then assembled onto the steel frame using wooden couplers for secure attachment. To facilitate the drying process, an air conditioning unit was installed inside the cabin (inbox) along with a blower (outbox) to regulate airflow. Finally, wheels were installed on the base of the machine to provide mobility and ease of access when loading salt into the drying cabin.

The salt drying machine is designed with practicality and efficiency in mind, starting with its primary structure, which is made from ST37 steel hollow type. This material was chosen due to its affordability and widespread availability, making it a suitable choice for a cost-effective yet durable framework. The sides of the machine are lined with plywood, which serves as an effective heat insulator. This ensures that the heat generated during the drying and cooling processes remains contained within the machine, preventing it from escaping into the external environment. This insulation is crucial for maintaining consistent internal temperatures and improving energy efficiency. Picture of salt dryer machine is shown on Figure 1.

Figure 1. Salt dryer machine

2.2 Research variable

In this research, the independent variables are temperature and fan speed during the salt drying process. Fan speed has three levels namely 3, 5, and 7 m^3/minute. Temperature has level, 18, 20 and 22°C. the dependent variable is energy consumption during the drying process. Each combination variable had three replications. Replication is crucial in research as it ensures the reliability and validity of findings [26]. By repeating experiments or studies under the same conditions, researchers can confirm that the results are consistent and not due to random chance or errors [27]. Replication enhances the credibility of the research, allowing conclusions to be more widely accepted and applicable [28]. It also helps identify any potential flaws or variables that were not initially considered, contributing to more robust and trustworthy scientific knowledge [29, 30]. The orthogonal matrix used in this research for optimization through the Taguchi method, applying the "smaller is better" quality control approach. The aim of this research is to find the optimal settings for energy consumption in volts by adjusting two key parameters: temperature during the salt drying process and fan speed. By analyzing the interaction of these variables, the research seeks to identify conditions that minimize energy usage while maintaining efficiency. In addition, the effect of the dependent variable on the independent variable is also observed, as well as the level of contribution. In addition, the effect of the dependent variable on the independent variable is also observed, along with the level of contribution. these observations use the general linear ANOVA model. The orthogonal matrix is shown in Table 1.

Table 1. Matrix orthogonal L_9 (3^2)

Combination	Temperature (°C)	Fan Speed (m^3/minute)
1	18	3
2	18	5
3	18	7
4	20	3
5	20	5
6	20	7
7	22	3
8	22	5
9	22	7

2.3 ANOVA analyse step

In this research ANOVA start from calculate the signal-to-noise (S/N) ratio, commonly used in quality engineering and experimental design, the S/N ratio is determined based on the objective of the experiment. For "smaller-is-better" characteristics, the S/N ratio is calculated as:

$$\eta = -10log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i}\right) \tag{1}$$

where, n is the number of trials and y_i is the observed value of the response. After obtaining the S/N ratios, an analysis of variance (ANOVA) is conducted to determine the statistical significance of the factors affecting the response. The steps for conducting ANOVA include calculating the total sum of squares (SST), which represents the total variation in the data:

$$SST = \sum_{i=1}^{N}(y_i - \bar{y})^2 \tag{2}$$

where, N is the total number of observations and $\bar{y}$ is the grand mean. Then, the sum of squares for each factor (SSA) is computed, along with the sum of squares for error (SSE). ANOVA involves partitioning the total sum of squares into contributions from each factor, followed by computing the mean square (MS) values by dividing each SSA and SSE by their respective degrees of freedom. Finally, F-values are calculated by dividing the MS of each factor by the MS of the error, allowing researchers to determine the statistical significance of each factor's impact on the response.

2.4 Salt dryer machine setup

Key features of the salt drying machine is its use of AC compressors to manage heat during the cooling phase. In many household air conditioning systems, the heat absorbed by the compressor is typically released into the environment and wasted. However, the salt drying machine is designed to capture and utilize this excess heat. By repurposing the hot air from AC compressors, the machine not only optimizes the cooling process but also makes it a practical option for households that already have air conditioning systems installed. This feature reduces energy waste and offers a more sustainable approach to the cooling mechanism, making the machine both environmentally friendly and energy-efficient. Layout air conditioner compressor shown in Figure 2.

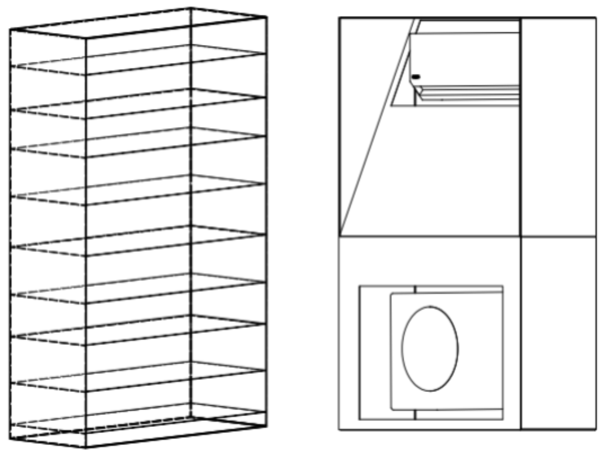

Figure 2. Placement scheme air conditioner compressor of dryer machine

Figure 3. Arduino AT Omega micro-controller

Figure 4. Micro-control position on salt dryer machine

An Arduino AT Omega micro-controller used to monitor and measurement of energy consumption rate during the salt drying process. This device provides real-time data on how much energy is being used, provide precise control and optimization of the drying operations. By integrating the Arduino AT Omega, operators can track energy usage and make adjustments to improve efficiency, ensuring that the machine operates at optimal levels while minimizing unnecessary energy consumption. The use of this microcontroller enhances the overall functionality and performance of the salt drying system, making it more efficient and user-friendly. Arduino AT Omega microcontroller shown on Figure 3. And the placement of this device shown on Figure 4 marked by red cycle.

3. RESULT AND DISCUSSION

3.1 Experimental result

This study aims to find the optimal parameters of temperature and fan speed variables, to minimise energy consumption during the salt drying process. the experimental results are shown in Table 2.

Table 2. Experimental result

Combination	Energy Consumption Replication 1 (W)	Energy Consumption Replication 2 (W)	Energy Consumption Replication 3 (W)	Average Energy Consumption (W)
1	5,066	5,418	5,992	5,492
2	5,126	5,438	5,817	5,460.333333
3	4,770	5,097	5,396	5,087.666667
4	4,376	4,688	4,997	4,687
5	4,806	4,997	5,264	5,022.333333
6	5,055	5,359	5,655	5,356.333333
7	4,417	4,735	5,037	4,729.666667
8	4,771	4,969	5,213	4,984.333333
9	5,087	5,389	5,696	5,390.666667

Based on Table 2, the lowest energy consumption achieved in specimen 4 with combination fan speed 3m^3/minute and drying temperature is 20℃ on first replication. The highest energy consumption achieved on specimen 3m^3/minute and third replication. On this specimen using combination temperature 18℃ and fan speed low. On average, the lowest energy consumption was achieved in the combination of temperature 20℃ and low fan speed, while the highest energy consumption is in combination temperature 18℃ and fan speed 3m^3/minute. on average energy consumption has a slight difference.

3.2 Optimization using Taguchi L_9

Based on these results, the optimal parameters were analysed using Taguchi L_9. Taguchi results are shown in Figure 5 (mean analysis) and Figure 6 (analysis based on S/N ratio). The culmination of the Taguchi L_9 analysis reveals that the optimal parameter configuration for the salt dryer machine is characterized by a 3m^3/minute fan speed setting in conjunction with a drying temperature of 20℃. Through the systematic experimentation and analysis, this specific combination emerged as the most favourable arrangement to achieve enhanced energy efficiency and effective salt drying. Using different materials to be dried, the following series of studies successfully optimised the parameters of their dryers using Taguchi L_9 [31]. The signal-to-noise ratio and mean response both consistently indicated that this particular configuration led to minimized energy consumption while maintaining the desired quality of the dried salt. The Taguchi L_9 methodology, renowned for its ability to efficiently explore multiple variables, underscores the significance of this finding. The low fan speed not only reduces energy consumption but also ensures a controlled drying environment, while the selected temperature of 20℃ strikes a balance between preservation of product quality and resource optimization. These results contribute to the advancement of sustainable industrial practices by providing a clear guideline for parameter adjustment, ultimately promoting the efficient operation of the salt dryer machine while aligning with energy conservation objectives [32]. Figures 5 and 6 also reveal instances where the S/N ratio is maximized and the mean response is optimized correspond to specific combinations of fan speed and drying temperature, highlighting the necessity of careful parameter control. This strong interaction implies that adjustments to only one parameter, without considering the other, might not yield the desired outcomes in terms of energy consumption and drying effectiveness. Therefore, a comprehensive approach that takes into account the joint influence of fan speed and drying temperature is imperative for achieving the best possible operational efficiency and salt drying quality in the machine.

The interpretation of the interaction plot based on signal-to-noise (S/N) ratio and mean plots reveals a substantial interdependence between the parameters of fan speed and drying temperature within the context of the salt dryer machine

[33, 34]. Based on Table 3, the S/N ratio a pivotal metric in the Taguchi methodology, provides insights into the quality of the drying process with respect to energy consumption. The mean plot, on the other hand, illustrates the overall average response of the system under different combinations of fan speed and drying temperature. Analysing these plots in tandem, it becomes evident that the interaction between fan speed and drying temperature has a pronounced impact on both the quality of drying and energy efficiency [6].

Figure 5. Result of optimisation based on mean plot

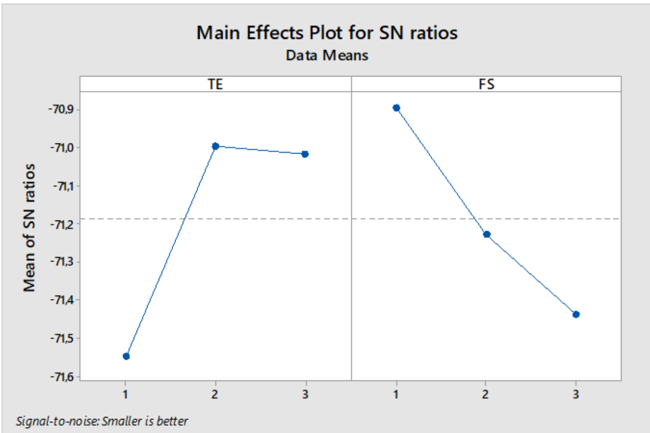

Figure 6. Result of optimisation based on S/N ratio plot

Table 3. Result of general linear model ANOVA

Source	DF	Seq SS	Contribution	F-Value	P-Value
TE	2	32.8889	94.27 %	37.00	0.003
FS	2	0.22222	0.64%	0.25	0.790
Error	4	1.7778	5.10%		
Total	8	34.8889	100.00%		

3.3 ANOVA analysis

General Linear ANOVA was utilized to determine contribution of parameter fan speed and temperature on salt dryer machine. Result of general linear ANOVA analyse is shown in Table 3.

Table 3 reveals parameter drying temperature is dominant compared to parameter fan speed. Parameter fan speed has contribution 0.64% and parameter dryer temperature process has contribution 94.7%. Energy consumption the experimentation revealed that varying temperature and fan speed levels significantly influence energy usage while maintaining the desired quality of dried salt. By analysing the signal-to-noise ratios, it became evident that specific combinations of temperature and fan speed contributed to minimized energy consumption. The interaction between these variables was found to be non-linear, highlighting the complexity of the drying process. Moreover, the ANOVA analysis demonstrated the dominant role of temperature in affecting energy efficiency, emphasizing its importance as a primary control parameter. The results also underscored the significance of ANOVA method in efficiently exploring multiple factors and interactions within a limited number of experiments, which is particularly advantageous for resource-constrained industrial settings. Overall, the outcomes of this study provide a foundation for the informed design and operation of energy-efficient salt drying systems, while showcasing the broader applicability of the Taguchi L_9 method in optimizing various industrial processes.

Based on experimental and data analyse, can be summarized drying process for salt is influenced by key variables such as drying temperature and fan speed, which are directly proportional to energy consumption. As the drying temperature increases, fan speed typically rises as well to ensure proper airflow and drying efficiency. This correlation leads to an upward trend in energy consumption, as higher temperatures demand more electricity. Specifically, the compressor in this system plays a significant role in overall energy usage. As the temperature setting is increased, the compressor must work harder to maintain the desired conditions, resulting in greater energy consumption. The system's efficiency is closely tied to the balance between temperature, fan speed, and compressor performance. The compressor plays a key role in the energy consumption of salt drying systems, as it regulates airflow and maintains the necessary temperature and humidity levels. As the drying temperature increases, the compressor must work harder to sustain optimal conditions, leading to a rise in electricity usage. This direct relationship means that higher temperature settings cause the compressor to run more frequently and intensively, significantly impacting overall energy consumption.

3.4 Experimental result

The main effects plot shows the impact of two factors, temperature (TE) and fan speed (FS), on the energy consumption of a dryer machine. As temperature increases from level 1 to level 2, there is a sharp reduction in energy consumption. However, beyond level 2, the energy consumption stabilizes, with no significant change observed at higher temperature levels. In contrast, fan speed shows a linear relationship with energy consumption; as the fan speed increases from level 1 to level 3, energy consumption rises consistently. This suggests that, for optimizing energy efficiency, reducing fan speed and maintaining temperature at or near level 2 could minimize energy use without compromising performance.

Figures 7 and 8 display the interaction plot between variable independent that was observed in this research. The interaction plot provides valuable insights into the relationship between drying temperature (TE) and fan speed (FS) during the drying process. The plot shows that the effects of temperature on the outcome drying efficiency or energy consumption vary depending on the fan speed level. At lower temperature levels 18°C, there is a significant difference between fan speed levels, with the highest fan speed 3m^3/minute yielding the highest values. However, as the temperature increases to 20°C and 22°C, the differences between fan speed levels become less pronounced, and the results stabilize. This suggests that at higher temperatures, the impact of fan speed is reduced. Conversely, the right side of the plot indicates that fan speed plays a more prominent role at lower temperatures, with Fans peed 3m^3/minute showing a steep decline as the temperature increases, while fan speed 5m^3/minute and fan speed 7m^3/minute maintain a more consistent trend. The non-parallel lines in the plot confirm a significant interaction between temperature and fan speed, highlighting the need to optimize both factors simultaneously for an efficient drying process.

Descriptive statistical graph, showing the variable fan speed and drying temperature are directly proportional. the higher the fan speed and drying temperature, the rate of electrical energy consumption in the drying machine system. The higher the fan speed setting, the faster the axial compressor in the system will rotate, the faster the compressor rotation requires more and more electrical energy. This similar reported by researches [35, 36]. The higher the drying temperature setting, the faster the evaporator will evaporate freon. The evaporation process requires electrical energy, so the more energy it consumes, this was also the case in the research [37]. Figure 9 reveals that the energy consumption at fan speed 7 is higher than the electrical energy consumption at 3 and 5. Figure 9 shows a graph of fan speed and drying temperature against energy consumption.

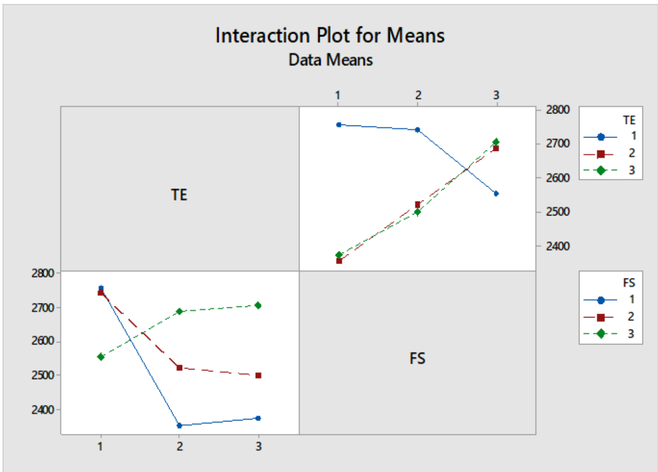

Figure 7. Result of interaction based on mean plot

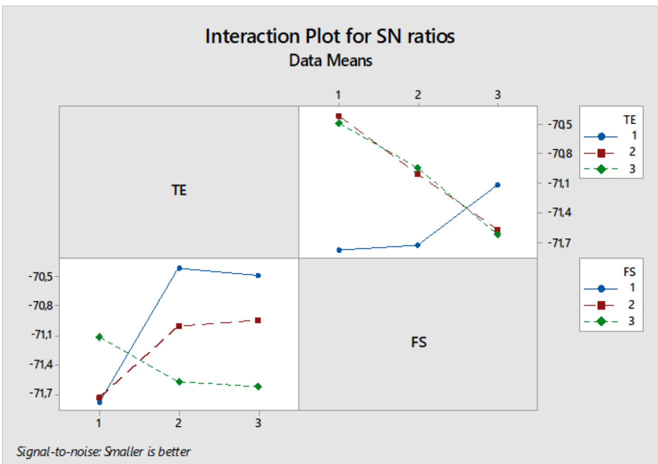

Figure 8. Result of interaction based on S/N ratio plot

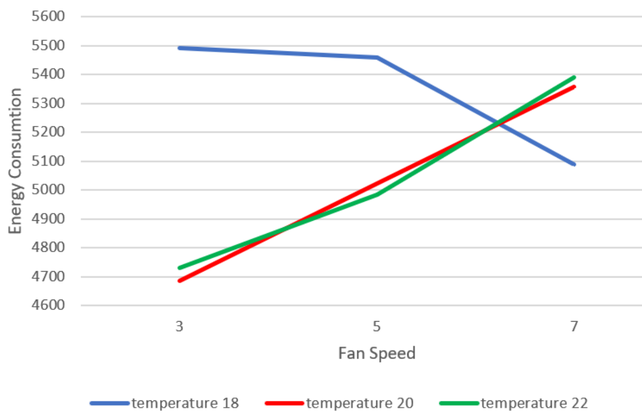

Figure 9. Comparison chart of fan speed and drying temperature energy consumption

Current research conducted dryer machine by applying step down microwave-hot air belt to drying Namdokmai Sithong mango slices [38]. In that research, the energy consumption is higher of 28,800 W, but the advantage is that it can dry contiguously due to the use of belts in the drying stage. When compared to the drying machine in our study, it has a complex method to be operated in rural areas. This research provides important insights into the energy consumption of a salt dryer machine, which in this study ranged between 4,376W to 5,992W. While this energy range demonstrates the machine's functionality for effective salt drying. It is reported that this research also designed a drying machine for cocoa beans using a hybrid drying system, namely open sun and microwave [39]. The range of electrical energy consumption in the study was in the range of 2400W to 3200W. In this study, energy consumption is indeed lower when compared to this study, but the drying system in the study still depends on sunlight. While in this study the cooling system takes place in a closed manner. The use of fan speed is used to mimic the average wind speed in salt producing areas such as Pamekasan and Sumenep districts. While the temperature we use also mimics the average temperature in both districts. However, the limitations in this research have not been able to mimic the temperature in nature. In the future, it is necessary to use Smart Thermostats with machine learning technology to mimic natural conditions as has been done in the research [40]. Additionally, the drying capacity remains low, indicating room for improvement in scalability and efficiency. Practical improvements could include the installation of hybrid drying solar technology solutions as revealed in the research [41], to reduce the energy load during daylight hours, conserving electricity and making the machine more suitable for off-grid settings. While the machine optimally supports the salt drying process, monitoring the corrosion characteristics of the frame is crucial for ensuring long-term durability, especially given the high salt exposure that can accelerate material wear. These insights have practical implications for scaling this technology to rural and remote locations, where modifications for energy conservation and structural longevity are essential to enhance usability, reduce operational costs, and support broader adoption.

4. CONCLUSIONS

The purpose of this research is to develop a salt dryer machine, and get the right fan speed and drying temperature setting parameters in the drying process. In a salt dryer machine showcases a promising avenue for enhancing operational efficiency. After a series of experiment the lowest energy consumption found on this research is 4687W, achieved on temperature 20℃ and $3m^3$/minute of fan speed. The highest energy consumption found on research is 5492W, achieved on temperature 20℃ and $3m^3$/minute fan speed. Based on optimization of Taguchi L_9 methods, recommendation optimum combination is fan speed low, 20℃ on drying temperature to ensure optimum energy consumption operational. By identifying the optimal combination of temperature and fan speed levels, manufacturers can achieve a balance between energy savings and effective salt drying. Fan speed factor plays a very important role in energy consumption in salt drying machines in this research, based on the results of ANOVA 97.24% is contribution of fan speed factor. It is hoped that the research on this drying machine will be the beginning of an alternative for salt farmers in Madura as a method of drying salt that does not depend on the weather. The future research needs to be developed further, especially the characteristics of evaporation and crystallisation comparison between the conventional drying process and the machine developed in this research, so that it can develop better for use in the Madura salt industries.

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