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Performance Evaluation of Heat Pump Dryer in Specific Moisture Evaporation Rate for Various Herbal Leaves

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Abstract - **Drying is an important process followed in Siddha, Ayurveda, and Food processing industries for resisting the growth of Fungi and other germs. Heat pumping drying is one the promising technology where the drying is attained by the concept of refrigeration cycle to dry the herbal leaves with controlling the operating parameters like pressure, temperature, and humidity of the circulating air and without the influence of the atmosphere condition. In this proposed work a three-ton capacity heat pump dryer is designed and fabricated where R134a was used as a refrigerant with tray type drying chamber for testing the moisture removal rate of three different herbal leaves Tulsi (Ocimum tenuiflorum), curry leaves (Murraya koenigii), and Bermuda grass (Cynodon dactylon). The velocity, temperature, humidity, and pressure of circulating air are the predominant operating parameters that affect the Specific Moisture Evaporation Rate of the closed-loop heat pump dryer. The experiments were conducted at condition 2.5 m/s velocity, transient temperature, and humidity with an atmospheric pressure of circulating air, and the Moisture removal rate is evaluated for the given herbal leaves.**

Keywords - Heat pump dryer, Moisture removal rate, Food processing, leaf drying, Tulsi, Curry leaves, Bermuda grass

I. INTRODUCTION

Heat pump drying is one of the methods in which the drying of bio product can be prepared with no influence of atmospheric condition and the drying is achieved with less energy consumption. The medicinal plants have to be stored as dried products to avoid the development of fungi, yeasts, and bacteria. The relative humidity less than or equal to 60% is a suggested value to preserve the medicinal plant during storage for maintaining the good quality of the product [1]. A heat pump system under vacuum conditions is developed to dry the Moringa leaves and the moisture removal rate is increased by reducing the pressure of the circulation air significantly [2]. The integration of different drying technologies like a fluidized bed with the heat pump dryer [3], microwave drying and multi-flash drying, microwave and vacuum drying is produced a good result in dehydrating rate [4]. Ginger a medicinal product is dried in a tray-type dryer at different combination of slice size of the ginger, temperature, and the velocity of airflow, the result shows that the drying rate is affected by the properties of air like temperature, velocity, and the dimensions of the ginger slice [5]. Moringa oleifera which contains the higher quantity of micro and macronutrient content and the loss in nutrient content concerning the temperature was analysed, the better quantity of nutrients is attained at the drying temperature range of 40°C to 50°C, and the drying temperature for the Moringa leaves is maintained more than 50°C in the oven drying will cause for the unexpected nutrient loss [6]. The change in moisture content, hardness, antioxidant activity, and colour of kiwi fruit was investigated at the hot air and vacuum drying conditions for the vacuum pressure of 3kPa and the drying process temperature of 50, 60, and 70°C, the L-ascorbic acid is prevented better in vacuum drying compared to hot air drying [7]. The various drying technologies like Rotary drum dryer, Fluidized bed dryer, Pneumatic dryer, Agitated drum dryer, Solar dryer, Microwave dryer, and Far-infrared dryer, available in the conversion of biomass to biofuel are reviewed and the results were compared in the tabulated format, integrating the advanced system in the conventional dryer will promisingly increase the drying efficiency [8].

Drying the product cassava in a fluidized bed dryer at three different mass flow rate of air with the temperature range of 60°C to 160°C for the interval of 20°C is analyzed, from the experimental result it is concluded that the drying time is decreased with increase in air flow rate and the temperature of the drying air [9]. The combined heat pump vacuum-microwave dryer has a 50% shorter drying time compared to heat pump-assisted drying and convective vacuum-microwave drying for the drying product apple [10]. The solar-assisted heat pump dryer was developed to dry banana chips and the drying rate of the developed model is compared with simple heat pump drying, infrared-assisted heat pump drying, solar-assisted heat pump drying. The results indicate that the specific moisture extraction rate is observed higher in the solar-assisted heat pump dryer than the other methods [11]. The promising low Global Warming Potential (GWP) refrigerants were used as working fluid in

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the batch type heat pump dryer and the performance of heat pump dryer in terms of specific moisture extraction rate, drying efficiency, coefficient of performance, product water activity, and exergy efficiency were investigated and it is suggested that the R152a can be used as a refrigerant in heat pump dryer for better performance, personal safety (less flammability) and environmental safety (low GWP) [12]. R134a is a relatively low-cost, non-flammable, non-toxic refrigerant and it is having a high heat recovery potential in the usage of heat pump dryer. The main drawback of using the R134a as a refrigerant in the heat pump dryer is high Global warming potential [13]. The closed-loop heat pump dryer is developed to dry the grape pomace and the analysis revealed, the effect of drying air temperature is large on the performance and energy consumption of the heat pump dryer [14]. Exergy analysis is the best tool to optimize the different types of energy systems, the exergy analysis was done on the important component of the heat pump dryer at the temperature range of 45°C to 55°C and the exergy efficiency value were increased from 65.94% to 91.95% when the drying air temperature is increased from the 45 to 55°C [15]. In this proposed experimental study a closed-loop heat pump dryer was designed and developed and the performance of that dryer was analysed for the three different medicinal important herbal leaves for the same velocity and transient temperature conditions.

II. MATERIAL AND METHODS

A. Materials

There are three herbal leaves Tulsi (Ocimum tenuiflorum), curry leaves (Murraya koenigii), and Bermuda grass (Cynodon dactylon) were selected to analyze the performance of the heat pump dryer. All the three leaves were purchased from the formers who were in and around the Rajapalayam.

B. Sample Preparation

The purchased leaves were completely cleaned with fresh distilled water to remove the unwanted particles which affect the drying rate of the product. After cleaned with water the products are kept in the paper which can absorb the water particle present on the surface of the leaves for at least 3 minutes. The leaves were purchased and prepared for drying then and there required to maintain the maximum moisture present in the leaves. The weight of the sample preparation for taking each reading is 10 kg.

A. Design and Development of Experimental Setup

1) Design

A 3-ton capacity refrigeration heat pump system is designed and developed to dry the different types of herbal leaves with the following specification components and the schematic diagram is given in Fig.1

TABLE I
SPECIFICATION OF COMPONENTS

Sl. No.	Components	Specifications
1.	Compressor	3-ton capacity – scroll compressor
2.	Evaporator	3-ton capacity – Copper coil – vertical finned type
3.	Condenser	3-ton capacity – Copper coil – vertical finned type
4.	Expansion device	3-ton capacity expansion valve
5.	Fan	1.5 kW capacity – 2 Nos.
6.	Fabrication plate	G.I Plate with 5 mm thickness
7.	Drying tray	Stainless steel tray with the dimensions of 100 cm x 60 cm

2) Measuring Instruments

TABLE III
SPECIFICATION OF MEASURING INSTRUMENTS

Sl. No.	Measuring Instrument	Specifications
1.	Anemometer	0 – 45 m/s
2.	Temperature sensor	0 – 99 °C
3.	Humidity sensor	0 – 99 %

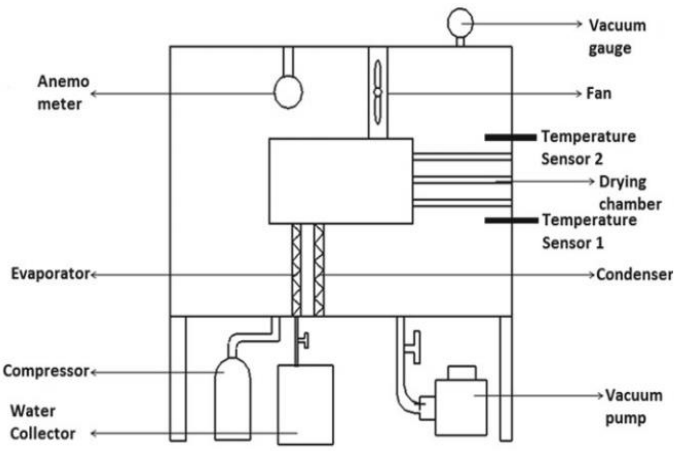

Fig. 1 Heat pump dryer

3) Operation

Drying is the process of removing moisture content in the product. In a heat pump dryer, the drying is achieved by sending dry air which can absorb the moisture through the product. The closed-loop heat pump dryer is consists of two important circuits 1. Refrigerant flow circuit and 2. Airflow circuit is shown in Fig.2 [16].

Refrigerant Flow Circuit

The refrigerant flow circuit represents the simple vapour compression refrigeration cycle. In the vapour compression refrigeration system, the latent heat of vaporization of Refrigerant R134a is utilized to observe the heat from the low-temperature space. The refrigerant flows through the four mandatory components compressor, condenser, expansion

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valve, and evaporator. The refrigerant coming out from the compressor at high pressure and high-temperature vapour is enters into the condenser where the phase change is occurring because of losses its latent heat to the air. The liquid refrigerant comes out from the condenser is entering the expansion device where the refrigerant pressure and temperature reduce and that is entered into the evaporator in which the refrigerant takes the heat from the surrounding air and the phase is changed from the liquid to the vapour form and enter into the compressor and the cycle continues.

Airflow Circuit

In the closed-loop heat pump dryer, the air inside the dryer is circulated through the evaporator, condenser, drying chamber, and the circulation of air is achieved by the fan provided between the condenser and drying chamber. While the air passing through the evaporator, it will reach the dew point temperature and condensation of moisture present in the air takes place so that the specific humidity of air is reduced and then the air is passed through the condenser where it will gain the heat from the refrigerant and the temperature of air increased.

Working Principle

The air leaves the evaporator with 100 % relative humidity losses its humidity when passing through the condenser because of increase in temperature of the air. The dry air with low relative humidity leaving from the condenser is entered into the drying chamber where the herbal leaves which has to be dried is placed. The low humidity air is having the capability to absorb the moisture present in the product because of the concentration difference of moisture present in the air and the product and the drying is achieved. The process flow diagram is given in Fig.3

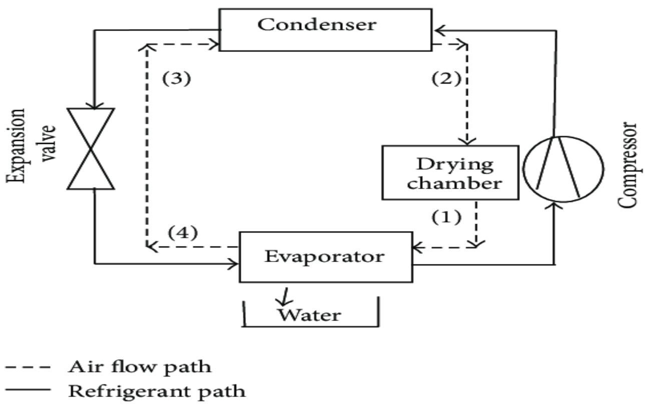

Fig. 2 Refrigerant and air flow circuit in Heat pump dryer

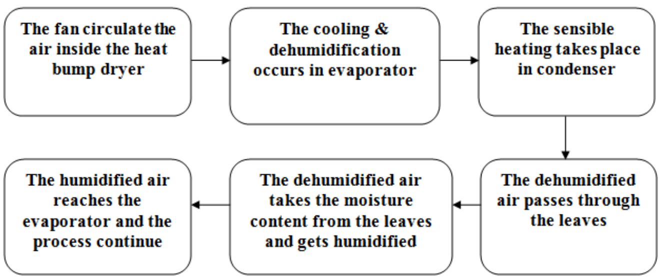

Fig. 3 Process flow diagram

B. Methods

1) Evaporation Rate

The leaves are taken from the drying chamber and the weight is measured immediately to avoid the natural convection mass transfer. The evaporation rate is being calculated by using the following equation [17].

$$\dot{m}_{ev} = \frac{m_t - m_f}{t}$$

Where,

m_t is the mass of product before drying in grams

m_f is the mass of product after drying in grams

t is drying time in seconds

III. RESULT AND DISCUSSION

The experiments were conducted in three different herbal leaves Tulsi (Ocimum tenuiflorum), curry leaves (Murraya koenigii), and Bermuda grass (Cynodon dactylon) at an air velocity of 2.5 m/s for the drying time of 1 hour and the evaporation rate for each one of the leaves are calculated. The change in temperature and humidity of air at inlet and outlet of the drying chamber for Tulsi leaves is shown in Fig.4, Fig.5, for curry leaves is shown in Fig.6, Fig.7, and that for the Bermuda grass is shown in Fig.8 and Fig.9. From Fig.4, Fig.6 and Fig.8 it is concluded that the temperature of the air at the outlet is lower than that of the inlet and the temperature difference at inlet and outlet is increased in Tulsi and Curry leaves and decreased to Bermuda grass. Both inlet and outlet temperatures are increased continuously for all the leaves. In the closed-loop heat pump dryer, the atmospheric condition has not affected the properties of circulated air so that the same air is circulated continuously will causes the temperature increase because of continuous rejection of heat from the condenser.

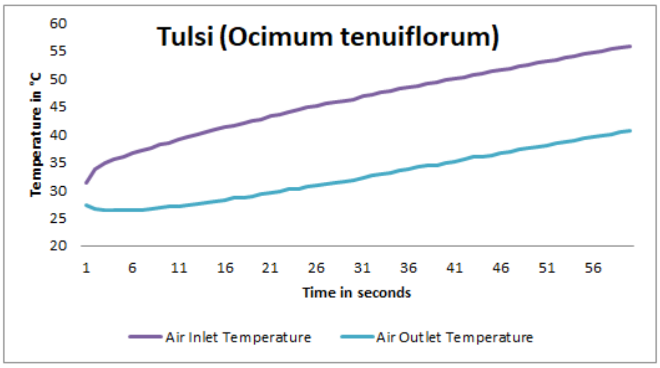

Fig.4 Time Vs Temperature for Tulsi leaves

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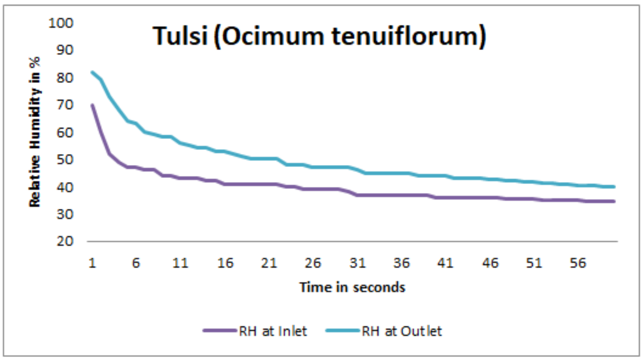

Fig.5 Time Vs Relative humidity for Tulsi leaves

The air enters into the drying chamber at high temperature and low Relative humidity and leaves at low temperature and higher humidity. The temperature of the air decreases because of increasing the moisture content which is taken from the herbal leaves.

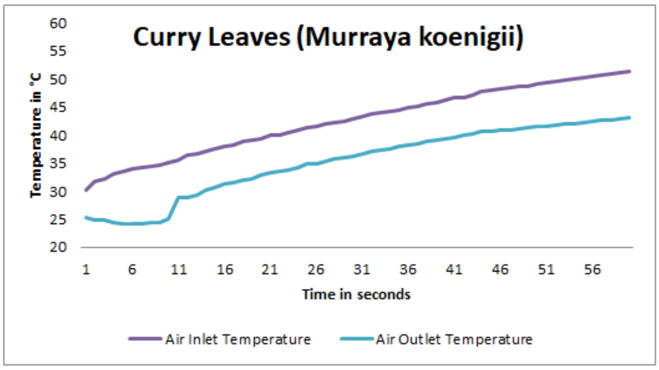

Fig.6 Time Vs Temperature for Curry leaves

From graphs Fig.5, Fig.7 and Fig.9 it is clear that the Relative humidity of air is increased at the outlet and the relative humidity is decreased continuously over time. The relative humidity of air is increased because the air passes through the drying chamber is taking the moisture content from the leaves which is present in the drying chamber and the relative humidity is decreased continuously for time because of the increase in temperature of air concerning time.

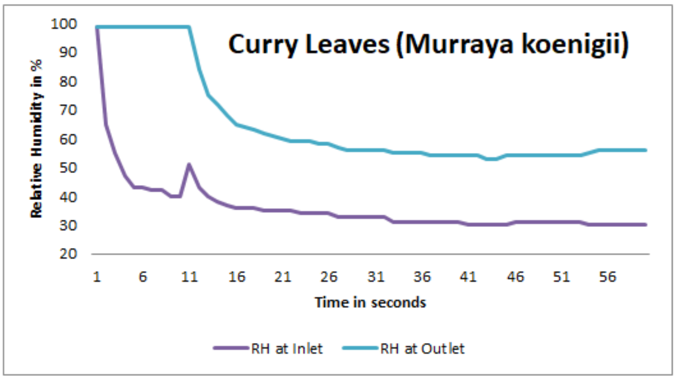

Fig.7 Time Vs Relative humidity for Curry leaves

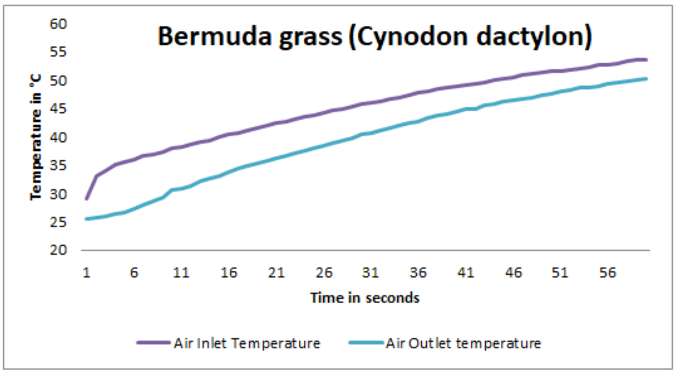

Fig.8 Time Vs Temperature for Bermuda grass

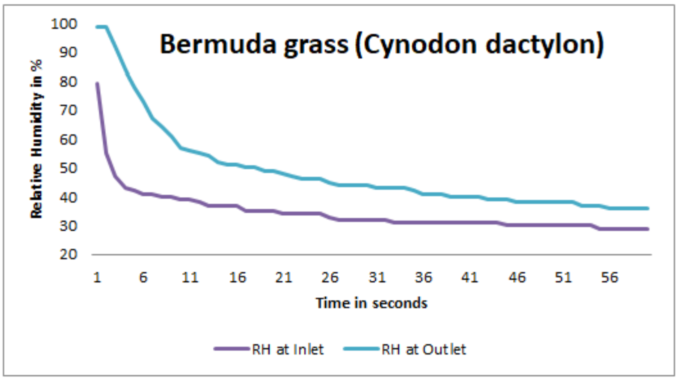

Fig.9 Time Vs Relative humidity for Bermuda grass

The Evaporation rate for the three different herbal leaves is shown in Fig.10. The overall evaporation rate for the Tulsi is lower than the curry leaves and the Bermuda grass. The highest value of Specific moisture evaporation rate is attained in the Bermuda grass. The specific moisture evaporation rate is the evaporation rate to the power consumed. The power consumption is the same for one hour of operation in the heat pump dryer for the same velocity. The experiments were conducted for all the herbal leaves at the same velocity so that there is no change in the power consumption per hour.
The density of Tulsi leaves is higher than the curry leaves and Bermuda grass and the Bermuda grass have the lower density among these three herbal leaves. So the density of the leaves is the important characteristic that affects the specific moisture evaporation rate in the close loop heat pump dryer at the vertical airflow condition.

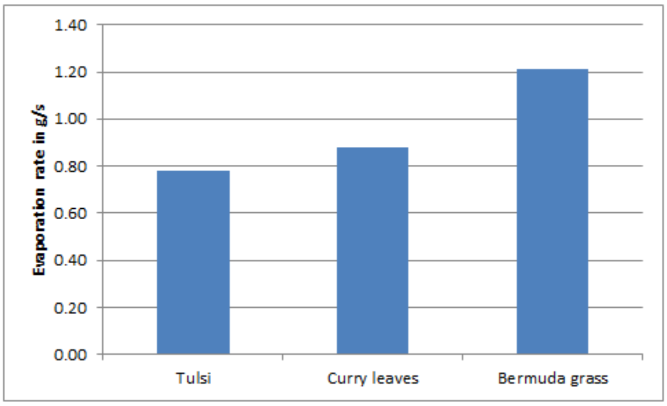

Fig.10 Evaporation rate for various herbal leaves

IV. CONCLUSION

The closed-loop heat pump dryer is designed and fabricated for drying the various herbal leaves which are having different densities and sizes. The experiments were conducted to calculate the specific moisture evaporation rate of Tulsi, curry leaves and Bermuda grass. The following points are concluded from the experimental results:

- The temperature air circulating air is continuously increased in close loop heat pump dryer and the evaporation rate is directly proportional to the temperature of the air.
- The relative humidity of the air is decreased continuously and the evaporation rate inversely proportional to the Relative humidity.
- The density and size of the leaves are the predominant characteristics that affect specific moisture evaporation rate and moisture removal rate.

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REFERENCES

[1] A. N. M. Alamgir, "Herbal drugs: Their collection, preservation, and preparation; evaluation, quality control, and standardization of herbal drugs," in Progress in Drug Research, 2017.
[2] M. Ashok Kumar, G. Kumaresan, and S. Rajakarunakaran, "Experimental study of moisture removal rate in Moringa leaves under vacuum pressure in closed-loop heat pump dryer," Materials Today: Proceedings, no. xxxx, pp. 2–7, 2020, doi: 10.1016/j.matpr.2020.04.244.
[3] N. S. Haron, J. H. Zakaria, and M. F. Mohideen Batcha, "Recent advances in fluidized bed drying," IOP Conference Series: Materials Science and Engineering, vol. 243, no. 1, 2017, doi: 10.1088/1757-899X/243/1/012038.
[4] R. L. Monteiro, J. V. Link, G. Tribuzi, B. A. M. Carciofi, and J. B. Laurindo, "Microwave vacuum drying and multi-flash drying of pumpkin slices," Journal of Food Engineering, 2018, doi: 10.1016/j.jfoodeng.2018.03.015.
[5] B. Haryanto, R. Hasibuan, Alexander, M. Ashari, and M. Ridha, "Herbal dryer: Drying of ginger (zingiber officinale) using tray dryer," IOP Conference Series: Earth and Environmental Science, vol. 122, no. 1, 2018, doi: 10.1088/1755-1315/122/1/012093.
[6] S. A. J, T. K. C, and A. R. I, "Effect of drying temperature on the nutritional quality of Moringa oleifera leaves," African Journal of Food Science, vol. 9, no. 7, pp. 395–399, 2015, doi: 10.5897/ajfs2014.1145.
[7] T. Orikasa et al., "Impacts of hot air and vacuum drying on the quality attributes of kiwifruit slices," Journal of Food Engineering, 2014, doi: 10.1016/j.jfoodeng.2013.10.027.
[8] J. Yi, X. Li, J. He, and X. Duan, "Drying efficiency and product quality of biomass drying: a review," Drying Technology, vol. 38, no. 15, pp. 2039–2054, 2020, doi: 10.1080/07373937.2019.1628772.
[9] I. O. Oluwaleye and M. B. Adeyemi, "Experimental Evaluation of a Batch Hot Air Fluidized Bed Dryer," International Journal of Modern Engineering Research (IJMER), 2013.
[10] C. H. Chong, A. Figiel, C. L. Law, and A. Wojdyło, "Combined Drying of Apple Cubes by Using of Heat Pump, Vacuum-Microwave, and Intermittent Techniques," Food and Bioprocess Technology, 2014, doi: 10.1007/s11947-013-1123-7.
[11] A. Singh, J. Sarkar, and R. R. Sahoo, "Experimental performance analysis of novel indirect-expansion solar-infrared assisted heat pump dryer for agricultural products," Solar Energy, vol. 206, no. June, pp. 907–917, 2020, doi: 10.1016/j.solener.2020.06.065.
[12] A. Singh, J. Sarkar, and R. R. Sahoo, "Comparative analyses on a batch-type heat pump dryer using low GWP refrigerants," Food and Bioproducts Processing, vol. 117, no. 2008, pp. 1–13, 2019, doi: 10.1016/j.fbp.2019.06.009.
[13] J. F. Wang, C. Brown, and D. J. Cleland, "Heat pump heat recovery options for food industry dryers," International Journal of Refrigeration, vol. 86, pp. 48–55, 2018, doi: 10.1016/j.ijrefrig.2017.11.028.
[14] M. Aktaş, L. Taşeri, S. Şevik, M. Gülcü, G. Uysal Seçkin, and E. C. Dolgun, "Heat pump drying of grape pomace: Performance and product quality analysis," Drying Technology, vol. 37, no. 14, pp. 1766–1779, 2019, doi: 10.1080/07373937.2018.1536983.
[15] Z. Erbay and A. Hepbasli, "Advanced Exergy Analysis of a Heat Pump Drying System Used in Food Drying," Drying Technology, vol. 31, no. 7, pp. 802–810, 2013, doi: 10.1080/07373937.2012.763044.
[16] F. Fayose and Z. Huan, "Heat pump drying of fruits and vegetables: Principles and potentials for Sub-Saharan Africa," International Journal of Food Science. 2016, doi: 10.1155/2016/9673029.
[17] R. N. Putra and T. A. Ajiwiguna, "Influence of Air Temperature and Velocity for Drying Process," in Procedia Engineering, 2017, vol. 170, pp. 516–519, doi: 10.1016/j.proeng.2017.03.082.