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Fuzzy Logic Modeling of Energy and Exergy Efficiencies in Drying Units Powered by Renewable Energy Sources

Ahmet ELBİR[1] **ORCID** *0000-0001-8934-7665*
Feyza AKARSLAN KODALOĞLU[*1] **ORCID** *0000-0002-7855-8616*
Mehmet Erhan ŞAHİN[2] **ORCID** *0000-0003-1613-7493*

[1]*Suleyman Demirel University, YEKARUM, Isparta, Türkiye*
[2]*Isparta Applied Science University, Technical Vocational High School, Isparta, Türkiye*

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Abstract

Today, exergy analyses have become essential for addressing critical engineering and environmental issues, such as improving energy efficiency, sustainable resource utilization, and reducing environmental impacts. To enhance the potential of these studies in generating more effective and precise results, new methods, like fuzzy logic, have been successfully employed in the analysis and decision-making processes. This article examines the energy and exergy analyses and integrating these analyses with fuzzy logic. The Organic Rankine Cycle systems, denoted as ORC-1 and ORC-2, exhibit energy efficiencies of 10.66% and 10.92%, respectively, with ORC-2 displaying an exergy efficiency increase to 86.8%. The cooling system boasts a Coefficient of Performance (COP) of 3.64 and an exergy efficiency of 25.3%. With fuzzy logic method, the estimated exergy efficiency for ORC-1 reached 99.38%, and the energy efficiency was estimated at 97.33%. For ORC-2, the exergy efficiency was estimated at 98.66%, and the energy efficiency was estimated at 99.42%. The refrigerant quantity for the cooling system was estimated at 97.7%, and the COP was estimated at 98.03%.

Keywords: Renewable energy, Energy and exergy efficiency, Fuzzy logic, Sustainability

Yenilenebilir Enerji Kaynakları ile Beslenen Kurutma Ünitelerinde Enerji ve Ekserji Verimlerinin Bulanık Mantık Modellemesi

Öz

Günümüzde ekserji analizleri, enerji verimliliği artırma, kaynakların sürdürülebilir kullanımı ve çevresel etkilerin azaltılması gibi kritik mühendislik ve çevre sorunlarını ele almak için vazgeçilmez hale gelmiştir. Bu çalışmaların daha etkili ve kesin sonuçlar üretme potansiyelini artırmak amacıyla, bulanık mantık gibi yeni yöntemler, analiz ve karar verme süreçlerine başarıyla uygulanmaktadır. Bu makalede, enerji ve ekserji analizleri ve bulanık mantık modellemesi incelenmiştir. ORC-1 ve ORC-2 olarak adlandırılan Organik Rankine Çevrimi sistemleri sırasıyla enerji verimliliği %10.66 ve %10.92'ye sahiptir, ancak ORC-2'nin

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[*] Sorumlu yazar (Corresponding Author): Feyza AKARSLAN KODALOĞLU, *feyzaakarslan@sdu.edu.tr*

ekserji verimi %86.8'e yükselir. Soğutma sistemi ise 3.64'lük bir COP değeri ve %25.3'lük ekserji verimine sahiptir. Bulanık mantık metodu ile: ORC-1 için ekserji verimliliği %99,38, enerji verimliliği ise %97,33 olarak tahmin edilmiştir. ORC-2 için ekserji verimliliği %98,66, enerji verimliliği ise %99,42 olarak tahmin edilmiştir. Soğutma sistemi için soğutkan miktarı %97,7, COP ise %98,03 olarak tahmin edilmiştir.

Anahtar Kelimeler: Yenilenebilir enerji, Enerji ve exerji verimi, Bulanık mantık, Sürdürülebilirlik

1. INTRODUCTION

The utilization of heat energy derived from renewable energy sources for drying units represents a significant objective in terms of energy efficiency. Consequently, energy efficiency and sustainability have become the focal points of industrial processes in recent years. In this context, our study aims to provide a new perspective on energy conversion and process efficiency by focusing on the unique combination of the Organic Rankine Cycle (ORC), refrigeration cycle, and drying unit. The detailed analysis of our integrated system highlights its features that enhance energy efficiency and emphasize environmental sustainability, thereby revealing significant potentials in industrial applications.

Some studies in the literature: In a study, Smart Fuzzy Controller and Fuzzy Rule Suram compared defuzzification methods based on environmental factors such as weather variables for the drying process. The results obtained show that the proposed approach has great potential in terms of performance. The smart fuzzy controller offered a smoother and more controllable performance than traditional controllers, and Fuzzy Rule Suram was found to be more efficient than the Smart Fuzzy Rule [1]. Another study provides a comprehensive review of fuzzy logic applications in the field of drying technology. Fuzzy logic applications are discussed systematically. Additionally, a road map for future studies for drying technology is presented [2]. Rahman et. al. He supported the experiments on vacuum drying of cocoa beans with mathematical models. The effects of temperature and pressure changes on drying speed and product quality were investigated. Experimental results showed that it is compatible with the fuzzy model. A suitable model for optimum drying has been proposed [3]. In another study, the convective-infrared drying behavior of white mulberry was examined and experimental data were obtained with different parameters. Humidity rate predictions were made with mathematical models and artificial neural network (ANN), and the results showed that the fuzzy model provides more accurate predictions than ANN and mathematical models [4]. Zoukit et. al. Takagi-Sugeno fuzzy (TSF) model was developed for hybrid solar-electric dryer. This model to predict the drying temperature has been tested with experimental data and a successful application has been achieved for the two main modes of the dryer (electric and solar) [5]. Gao and Liu aimed to develop a model for adapting geothermal ORC systems to different conditions and off-design performance. An optimal control strategy was presented by using turbine guide blade angle, coolant pump speed and cooling water flow rate as control variables. The results showed that the flow rate of geothermal water, inlet temperature and cooling water temperature were associated with increased net power production. Supercritical ORC generally produced a higher net power than subcritical ORC, but the difference has been shown to decrease under some conditions [6]. Yaïc et. al. He focused on underground heat pumps (GSHP) and organic Rankine cycle systems (ORC) and suggested combining these two systems in a parallel structure. The proposed integrated system has achieved more than 80% energy savings compared to conventional GSHP systems in different Canadian cities (Edmonton, Halifax, Vancouver). The ORC system increased the performance of the GSHP, offering higher COP values and reducing operating times [7]. Khan and Kim presented the thermodynamic analysis of an organic Rankine cycle system and water heating system that can operate at high temperatures. This system can produce 585.7 kW net power and also provide hot water at 35°C for home use. Seasonal air temperature and water temperature data from Seoul, South Korea were used for performance analysis. It is balanced according to the hot water need by using two different mass fractions. Performance analysis was carried out according to different working fluids and months [8]. In another study, the wool drying process in a heat pump dryer was examined. A fuzzy model was created using the fuzzy logic method, one of the artificial intelligence methods, to determine the effect of time, temperature, loading rate and air speed on the drying rate. Wet wool was used as the test material. While the air velocities at the inlet of the dryer varied between 0.8 m/s and 1.5 m/s, the material loading ratio (material/dryer volume) varied between 0.5 and 2.5. The inlet temperature of the dryer was varied between 40°C and 90°C. It was concluded that the obtained fuzzy logic results were compatible with the experimental results [9]. Kumaresan examined the optimization of the single-stage air source vapor compression heat pump system using genetic algorithm (GA) and fuzzy logic (FL) in order to use heat pumps, which offer economical alternatives to heat recovery from different sources, in industrial, commercial and residential applications. The properties required for thermodynamic optimization were calculated using fuzzy logic. Thermodynamic properties obtained by fuzzy logic were compared with real results. Then, the most suitable operating conditions of the heat pump system were determined by genetic algorithm [10].

This study constitutes a system developed with the aim of integrating the heat obtained from renewable energy sources into a drying unit, which is required for its operation. Simultaneously, it seeks to provide a detailed analysis of the energy and exergy efficiencies of the integrated sub-cycles using fuzzy logic methods. This study represents an important step in understanding the feasibility of the drying process with alternative energy exchange.

2. MATERIAL AND METHODS

2.1. System Description

In Figure 1, the design of the integrated system undergoing thermodynamic analysis is provided.

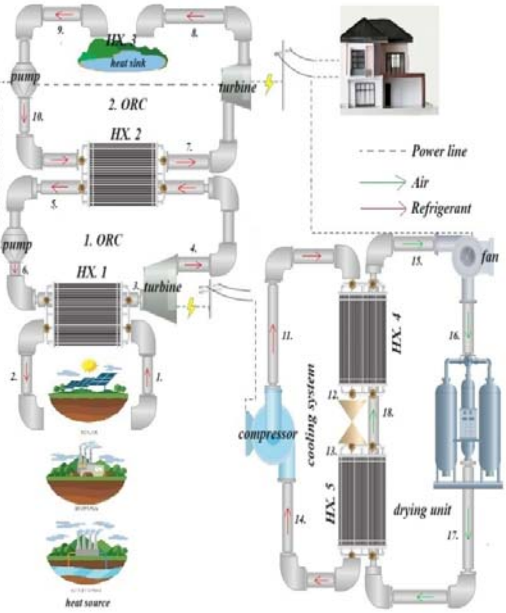


Figure 1. Integrated system undergoing thermodynamic analysis.

In the system in Figure 1, the heat taken from the heat source (solar, biomass, geothermal) at the 1st point is transferred to a sub-1st ORC system. 1. The power of the cooling system was met with the electrical power obtained in the ORC. The drying cycle is completed by connecting the cooling system to the drying unit. In addition, the electrical power of the fan in the drying unit and the indoor space in the facility was supplied by the 2nd ORC system connected to the 1st ORC.

2.2. Energy and Exergy Analyzes

In steady state, the mass balance equation can be given as follows [11,12]:

$$\sum \dot{m}_g = \sum \dot{m}_ç \tag{1}$$

where m is the mass flow rate, the indices g and ç are the inlet and outlet conditions, respectively. The energy balance is given in the equation below.

$$\dot{Q}_g + \dot{W}_g + \sum_g \dot{m}\left(h + \frac{V^2}{2} + gz\right) = \dot{Q}_ç + \dot{W}_ç + \sum_ç \dot{m}\left(h + \frac{V^2}{2} + gz\right) \tag{2}$$

Here, Q is the heat transfer rate, W is the power, h is the specific enthalpy, v is the velocity, z is the height, and g is the gravitational acceleration.

$$\sum_{in} \dot{m}_{in} s_{in} + \sum_{k} \frac{\dot{Q}}{T_k} + \dot{S}_{gen} = \sum_{ex} \dot{m}_{ex} s_{ex} \qquad (3)$$

where s is the specific entropy and $\dot{S}_{gen}$ is the entropy generation rate. The exergy balance equation can be written as:

$$\sum \dot{m}_{in}\, ex_{in} + \sum \dot{E}\, x_{Q,in} + \sum \dot{E}x_{W,in} = \sum \dot{m}_{ex} ex_{ex} + \sum \dot{E}x_{Q,ex} + \sum \dot{E}x_{W,ex} + \dot{E}x_D \qquad (4)$$

The specific flow exergy can be written as:

$$ex = x_{ph} + ex_{ch} + ex_{pt} + ex_{kn} \qquad (5)$$

The kinetic and potential parts of the exergy are assumed to be negligible. Also, the chemical exergy is assumed to be negligible. The physical or flow exergy (ex_{ph}) is defined as:

$$ex_{ph} = (h - h_o) - T_o(s - s_o) \qquad (6)$$

where h and s represent specific enthalpy and entropy, respectively, in the real case. h_o and s_o are enthalpy and entropy at reference medium states, respectively.

Exergy destruction is equal to specific exergy times mass;

$$\dot{E}x_D = ex * m \qquad (7)$$

$\dot{E}x_D$, are work-related exergy ratios and are given as:

$$\dot{E}x_D = T_0 \dot{S}_{gen} \qquad (8)$$

$\dot{E}x_W$, are work-related exergy ratios and are given as:

$$\dot{E}x_W = \dot{W} \qquad (9)$$

$\dot{E}x_Q$, are the exergy rates related to heat transfer and are given as below.

$$\dot{E}x_Q = \left(1 - \frac{T_o}{T}\right) \dot{Q} \qquad (10)$$

System thermal efficiency (η);

$$\eta = \frac{energy\ in\ exit\ outputs}{total\ energy\ inlets} \qquad (11)$$

The exergy efficiency (ψ) can be defined as follows;

$$\psi = \frac{exergy\ in\ exit\ outputs}{total\ exergy\ inlets} \qquad (12)$$

2.3. Assumptions and Fixed Parameters

1. The temperature in the heat exchangers is balanced, there is no heat loss.
2. Pressure losses in all parts of the system are neglected.
3. The isentropic efficiency of the pumps and compressor is 75%, and the isentropic efficiency of the turbine is 85%.
4. Changes in kinetic and potential energy are neglected.
5. System performance is assumed to be constant and regular.
6. The dead state of the fluids (air, R600a) circulating in all cycles was taken as temperature 293.2 K and 1 bar atmospheric pressure.

2.4. Fuzzy Logic

Fuzzy systems are knowledge-based systems constructed using fuzzy "if-then" rules, facilitating a systematic process of transforming information from non-linear functions to a knowledge base [13]. The fuzzy logic theory enables the incorporation of expert human knowledge into computer systems through the use of "if-then" rules. This, in turn, enables the successful utilization of linguistic data found in natural language and human thoughts. Fuzzy systems are composed of four main components: a fuzzy rule base, a fuzzy inference engine (decision-making unit), a fuzzifier, and a defuzzifier. The general structure of a fuzzy system is illustrated in Figure 2.

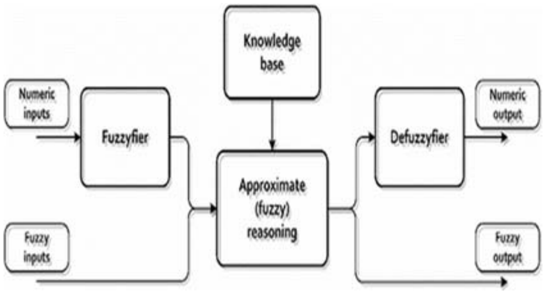


Figure 2. The typical structure of a fuzzy system [14]

Fuzzification is defined as the process of converting a crisp real value into a fuzzy set. In this process, the range of input variables is transformed into an appropriate universal set, allowing input values to be converted into suitable linguistic terms. During the fuzzification stage, preliminary preparations are made for the processing of externally received data using the information in the fuzzy rule base of the system. Various membership functions are employed in the fuzzification stage for this purpose. The most commonly used types of membership functions in applications are Triangular, Trapezoidal, Bell Curve, Gaussian, Sigmoidal, and Pi (π) membership functions [15]. Researchers often prefer heuristic methods and artificial intelligence techniques such as ant colony algorithms, clonal selection algorithms, tabu search algorithms, genetic algorithms, and artificial neural networks to determine these membership functions [16-19]. In this study, based on a detailed literature review and expert opinions in the field, triangular membership functions were employed.

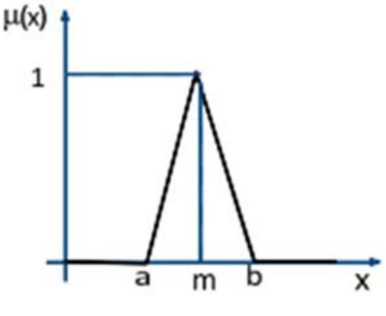


Figure 3. Triangular membership function

In the fuzzy inference section, a rule base is used in conjunction with an inference mechanism for information presentation. Once the incoming data is prepared for processing within the fuzzy rule base, it is then processed by the inference mechanism according to the "if-then" rules defined. The variables, the number of membership functions, and the number of rules are the components in this context, and structural learning occurs based on these defined parameters. Within the fuzzy inference mechanism, information is modeled through various methods. These inference methods, known as Mamdani method, Larsen method, Tsukamoto method, and Tagaki-Sugeno-Kang method, are utilized [20,21]. Within the Mamdani inference method used in this study, the threshold values for rules are calculated using the "and (intersection)" operator first, followed by the "or (union)" operators.

The defuzzification stage involves the process of converting the fuzzy set obtained in the fuzzy inference engine into a precise value. To apply the resulting fuzzy set back to real-world scenarios, it must be represented numerically. The most commonly encountered defuzzification methods include the centroid method, the largest membership principle, the mean of maxima, the weighted average method, the smallest of largest, and the largest of maxima methods [22]. In this study, the centroid method was employed.

$$y^* = \frac{\sum_{i=1}^{n} y_i \cdot \mu_c(y_i)}{\sum_{i=1}^{n} \mu_c(y_i)} \tag{13}$$

The formula (13) is used to compute it, where yi represents the defined output variable value, μc(yi) stands for the membership degree of the output variable, and y* denotes the defuzzified value.

3. RESULTS

Figure 4 shows the T-s diagram for ORC-2 in the integrated system.

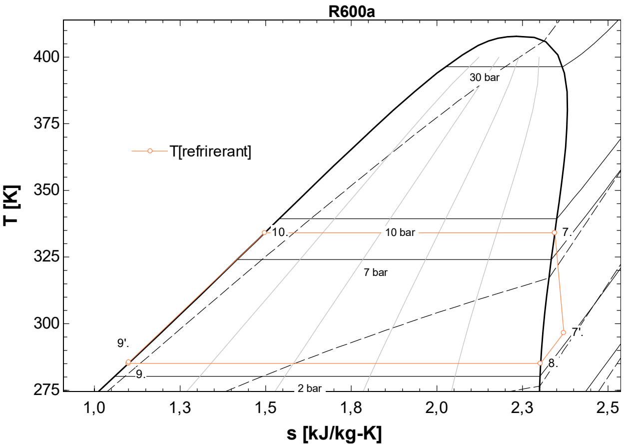


Figure 4. Temperature entropy conversion for ORC-2.

Thermodynamic properties of the positions in the T-s diagram in Figure 4 are given in Table 1. Figure 5 shows the T-s diagram for the cooling part of the integrated system.

Thermodynamic properties of the positions in the T-s diagram in Figure 5 are given in Table 2.

Figure 6 shows the T-s diagram for ORC-1 in the integrated system.

Table 1. Thermodynamic properties for ORC-2

Location	T [K]	P [bar]	x	h [kJ/kg]	s [kJ/kg.K]	ex[kj/kg]	m [kg/s]	Refrigerant
T0	293,2	1	-	590,6	2,487	-	-	R600A
7.	343,1	8,876	1	635,4	2,345	86,49	0,4646	R600A
7'.	296,5	2,345	100	590,9	2,371	34,19	0,4646	R600A
8.	285,1	2,345	1	571	2,303	34,36	0,4646	R600A
9.	285,1	2,345	0	227,9	1,099	44,14	0,4646	R600A
9'.	285,5	8,876	-100	229,4	1,101	45,28	0,4646	R600A
10.	334,1	8,876	0	352,3	1,497	51,85	0,4646	R600A

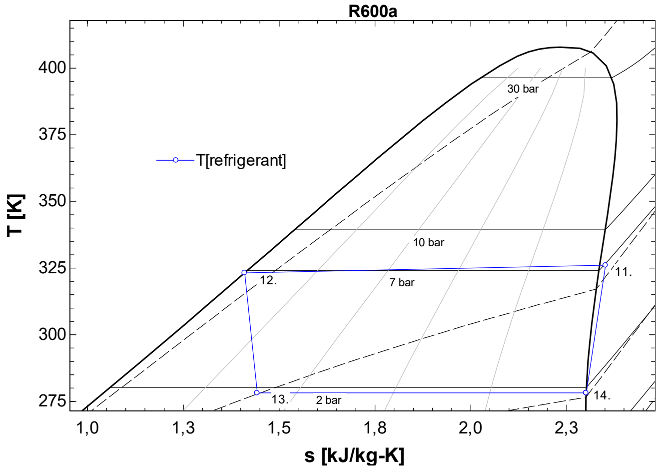


Figure 5. Temperature entropy cycle for cooling system

Table 2. Thermodynamic properties for the cooling system

Location	T [K]	P [bar]	x	h [kJ/kg]	s [kJ/kg.K]	ex[kj/kg]	m [kg/s]	Refrigerant
T0.	293,2	1	-	590,6	2,487	-	-	R600A
11.	326,1	6,853	100	291,7	2,351	76,61	0,3429	R600A
12.	323,2	6,853	0	323,1	1,41	48,35	0,3429	R600A
13.	278,2	1,867	0,3182	323,1	1,443	38,71	0,3429	R600A
14.	278,2	1,867	1	561,8	2,301	25,85	0,3429	R600A

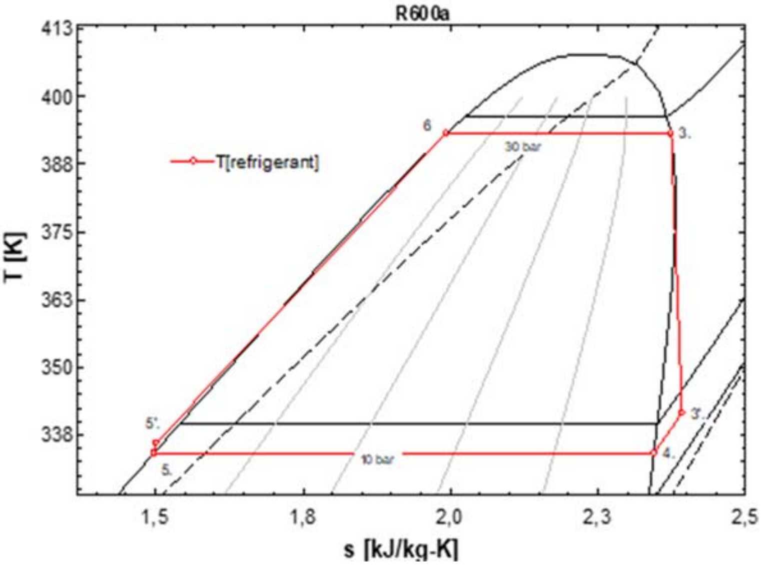


Figure 6. Temperature entropy conversion for ORC-1

Table 3 gives the thermodynamic properties of the positions of the T-s diagram in Figure 6.

In Table 4, thermodynamic properties for the drying unit are presented from the sub-components in the integrated system designed in Figure 1.

Table 5 presents energy and exergy efficiency values for a drying unit, two Organic Rankine Cycle (ORC) systems and a cooling system.

Table 3. Thermodynamic properties for ORC-1

Location	T [K]	P [bar]	x	h [kJ/kg]	s [kJ/kg.K]	ex[kj/kg]	m [kg/s]	Refrigerant
T0.	293,2	1	-	590,6	2,487	-	-	R600A
3.	393,2	28,4	1	687,1	2,374	129,7	0,6305	R600A
3’.	341,6	8,876	100	651,4	2,392	88,62	0,6305	R600A
4.	334,1	8,876	1	635,4	2,345	86,49	0,6305	R600A
5.	334,1	8,876	0	352,3	1,497	51,85	0,6305	R600A
5’.	336,1	28,4	-100	357,5	1,501	55,9	0,6305	R600A
6.	393,2	28,4	0	537,3	1,993	91,66	0,6305	R600A

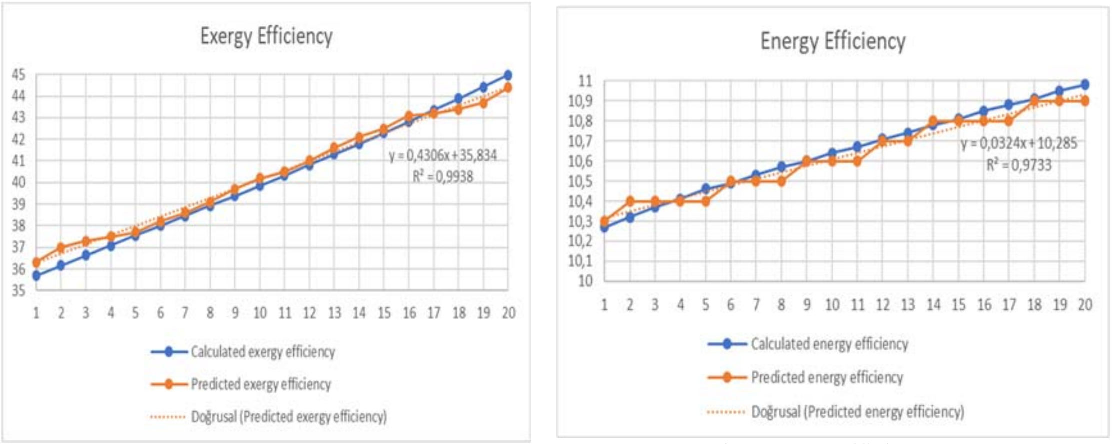
Table 4. Thermodynamic properties for the drying unit

Location	T [K]	P [bar]	x	h [kJ/kg]	s [kJ/kg.K]	ex[kj/kg]	m [kg/s]	Refrigerant
T0.	293,2	1	-	293,4	6,846	-	-	Air
15.	323,2	1	-	323,6	6,944	1,447	9,9333	Air
16.	323,2	1	-	323,6	6,944	1,447	9,9333	Air
17.	320,9	1	-	321,3	6,936	1,24	9,9804	Air
18.	312,8	1	-	313,1	6,911	0,6314	9,9804	Air

Table 5. Energy and exergy efficiencies of all components

Component	Energy efficiency [%]		Exergy efficiency [%]
Drying Unit	22.1		22.4
ORC-1	10.66		40.1
ORC-2	10.92		86.8
Cooling Unit	COP	3.64	25.3

In terms of thermodynamics, the results of the calculations in table 1, table 2, table 3 and table 4 are as follows: The drying unit uses 22.1% of the energy effectively, while its exergy efficiency is 22.4%. Moreover, Organic Rankine Cycle systems called ORC-1 and ORC-2 have energy efficiency of 10.66% and 10.92% respectively, but the exergy efficiency of ORC-2 increases to 86.8%. The cooling system has a COP value of 3.64 and an exergy efficiency of 25.3%.

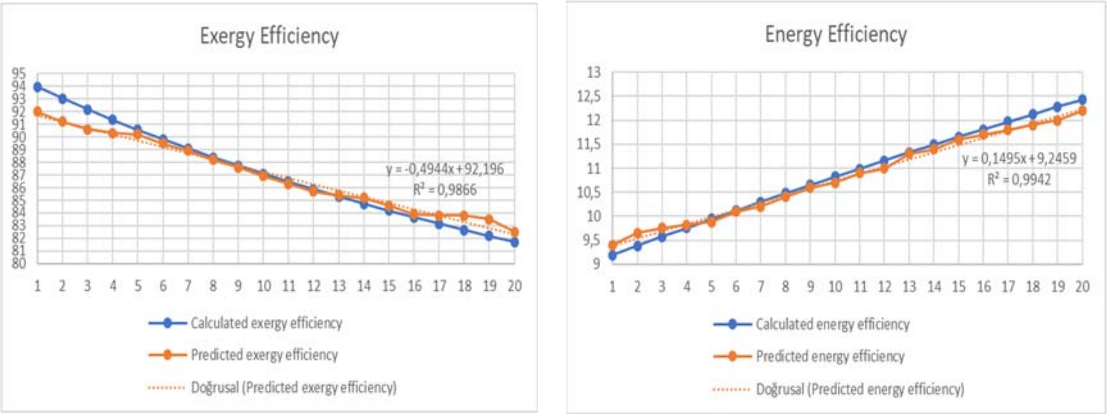


a) Exergy efficiency

b) Energy efficiency

Figure 7. Comparative results of a) exergy efficiency and b) energy efficiency analysis results calculated for ORC-1 and estimated values as a result of the fuzzy model

Comparative results of the calculated exergy and energy analysis results for ORC-1 and the predicted values as a result of the fuzzy model are shown in the Figure 7. Accordingly, exergy efficiency was estimated at 99.38% and energy efficiency was estimated at 97.33%.

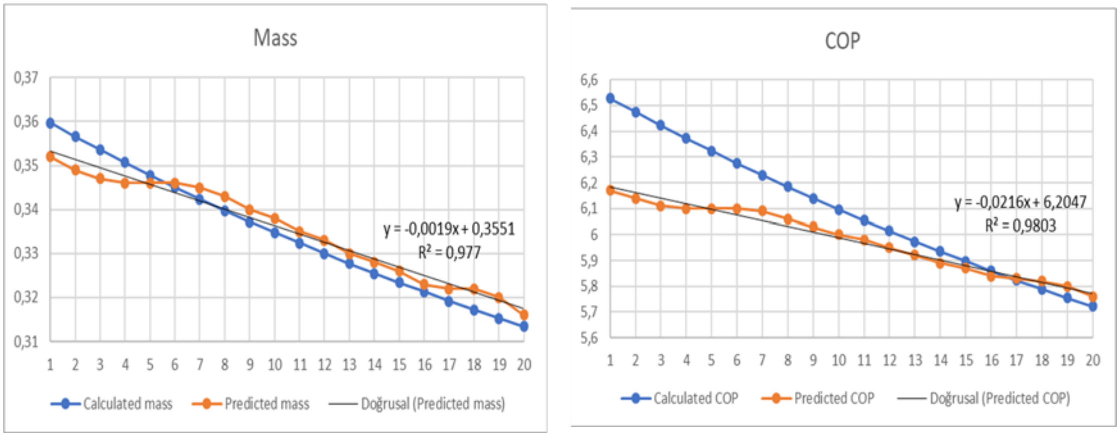


a) Exergy efficiency

b) Energy efficiency

Figure 8. Comparative results of a) exergy efficiency and b) energy efficiency analysis results calculated for ORC-2 and estimated values as a result of the fuzzy model

Comparative results of the calculated exergy and energy analysis results for ORC-2 and the predicted values as a result of the fuzzy model are shown in the Figure 8. Accordingly, exergy efficiency was estimated at 98.66% and energy efficiency was estimated at 99.42%.



a) Amount of refrigerant

b) COP

Figure 9. Comparative results of a) refrigerant amount and b) COP results calculated for the cooling system and the estimated values as a result of the fuzzy model

Comparative results of the calculated refrigerant amount and Coefficient of Performance results for cooling and the predicted values as a result of the fuzzy model are shown in the figure 9. Accordingly, the refrigerant amount was estimated at 97.7% and COP was estimated at 98.03%.

4. CONCLUSION

In this study, an integrated system has been designed for a drying unit that utilizes renewable energy sources as the required energy. The energy and exergy efficiencies of the sub-cycles of the integrated system have been thoroughly analyzed using fuzzy logic methods. The obtained results provide an important roadmap for enhancing the performance of energy systems and utilizing resources more efficiently. This work contributes to the more effective use of these analyses to achieve sustainable energy efficiency and environmental conservation goals. In this context, the results obtained for the designed system are as follows:

- Result of thermodynamic calculations: The drying unit uses 22.1% energy effectively, while its exergy efficiency is 22.4%. Moreover, Organic Rankine Cycle systems called ORC-1 and ORC-2 have energy efficiency of 10.66% and 10.92% respectively, but the exergy efficiency of ORC-2 increases to 86.8%. The cooling system has a COP value of 3.64 and an exergy efficiency of 25.3%.
- Fuzzy logic method results: exergy efficiency for ORC-1 was estimated at 99.38% and energy efficiency was estimated at 97.33%. For ORC-2, exergy efficiency was estimated at 98.66% and energy efficiency was estimated at 99.42%. The amount of refrigerant for the cooling system was estimated at 97.7% and COP was estimated at 98.03%.

Today, energy and exergy analyzes have become essential tools to provide effective solutions to important engineering and environmental problems such as sustainable energy use and environmental protection. In order to make the results of these analyzes more precise and efficient, modern calculation methods such as fuzzy logic are successfully used. In this article, in the integrated system designed in thermodynamic calculations; By examining a wide range of applications ranging from Organic Rankine Cycle systems, cooling systems and drying units, the use of fuzzy logic in energy and exergy analyzes has been contributed.

5. REFERENCES

1. Situmorang, Z., Husein, A.E., 2023. Comparison of Intelligent Fuzzy Controller and Fuzzy Rule Suram Algorithms in the Drying Process. Information Sciences Letters, 12(6), 2603-2621.
2. Hosseinpour, S., Martynenko, A., 2022. Application of Fuzzy Logic in Drying: A review. Drying Technology, 40(5), 797-826.
3. Rahman, S.A., Nassef, A.M., Rezk, H., Assad, M.E.H., Hoque, M.E., 2021. Experimental Investigations and Modeling of Vacuum Oven Process Using Several Semi-Empirical Models and a Fuzzy Model of Cocoa Beans. Heat and Mass Transfer, 57, 175-188.
4. Jahedi Rad, S., Kaveh, M., Sharabiani, V.R., Taghinezhad, E., 2018. Fuzzy Logic, Artificial Neural Network and Mathematical Model for Prediction of White Mulberry Drying Kinetics. Heat and Mass Transfer, 54, 3361-3374.
5. Zoukit, A., El Ferouali, H., Salhi, I., Doubabi, S., Abdenouri, N., 2019. Takagi Sugeno Fuzzy Modeling Applied to an Indirect Solar Dryer Operated in Both Natural and Forced Convection. Renewable Energy, 133, 849-860.
6. Gao, T., Liu, C., 2017. Off-Design Performances of Subcritical and Supercritical Organic Rankine Cycles in Geothermal Power Systems Under an Optimal Control Strategy. Energies, 10(8), 1185.
7. Yaïci, W., Annuk, A., Entchev, E., Longo, M., Kalder, J., 2021. Organic Rankine Cycle-Ground Source Heat Pump with Seasonal Energy Storage Based Micro-Cogeneration System in Cold Climates: The Case for Canada. Energies, 14(18), 5705.
8. Khan, B., Kim, M.H., 2022. Energy and Exergy Analyses of a Novel Combined Heat and Power System Operated by a Recuperative Organic Rankine Cycle Integrated with a Water Heating System. Energies, 15(18), 6658.
9. Akarslan Kodaloğlu, F., Elbir, A., Sahin, M.E., 2023. Wool Drying Process In Heat-Pump-Assisted Dryer by Fuzzy Logic Modelling. Thermal Science, 27(4 Part B), 3043-3050.
10. Kumaresan, G., 2013. Optimizing Design of Heat Pump Using Fuzzy Logic and Genetic Algorithm. International Journal of Engineering Research and Applications (IJERA), 3, 1184-1189.
11. Dincer, I, Rosen, M.A., 2012. Exergy: Energy, Environment and Sustainable Development. Elsevier Science, 551.

12. Cengel, Y.A., Boles, M.A., Kanoğlu, M., 2011. Thermodynamics: an Engineering Approach. New York: McGraw-Hill, 445.

13. Wang L.X., 1997. A Course in Fuzzy Systems and Control. New Jersey: Prentice Hall, 424.

14. Czabanski, R., Jezewski, M., Leski, J., 2017. Introduction to Fuzzy Systems. Theory and Applications of Ordered Fuzzy Numbers. 356, 23-43.

15. Elmas, Ç., 2003. Bulanık Mantık Denetleyiciler. Seçkin Yayıncılık, Ankara, 230.

16. Arslan, A., Kaya. M., 2001. Determination of Fuzzy Logic Membership Functions Using Genetic Algorithms. Fuzzy Sets and Systems, 118(2), 297-306,

17. Bağış, A., 2003. Determining Fuzzy Membership Functions With Tabu Search an Application to Control. Fuzzy Sets and Systems, 139(1), 209-225.

18. Jiang, H., Deng, H., He, Y., 2008. Determination of Fuzzy Logic Membership Function Using Extended Ant Colony Optimization Algorithm. Fifth International Conference on Fuzzy Systems and Knowledge Discovery (FSKD). Shandong, China, 1, 581-585,

19. Acilar A.M., Arslan, A., 2011. Optimization of Multiple Input-Output Fuzzy Membership Functions Using Clonal Selection Algorithm. Expert Systems with Applications, 38(3), 1374-1381.

20. Ross, T.J., 2004. Fuzzy Logic with Engineering Applications. John Wiley Sons Ltd, Chichester, 628.

21. Sivanandam, S.N., Sumathi, S., Deepa, S.N., 2007. Introduction to Fuzzy Logic Using MATLAB. Springer, Berlin, 430.

22. Şen, Z., 2020. Bulanık Mantık İlkeleri ve Modelleme. Su Vakfı, 368.

23. Klein, S.A., 2020. Engineering Equation Solver (EES) F-Chart Software, Version 10.835-3D.