Comparison of energy and exergy of food waste dryer in both reverse and non-reverse flow states

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Abstract: The increase in population growth and the demand for food supply and the high percentage of waste production in the food supply chain are among the reasons for increasing attention to the issue of waste management in the world. Due to its huge volume of important nutrients, food waste offers a lot of potential for animal feed production. The goal of this research was to examine the energy and exergy requirements for producing animal feed from food waste using a dryer in two states: reverse flow and non-reverse flow. Hot air is mixed with fresh air in reverse flow but in non-reverse flow fresh air is used. Food waste is collected from kitchen. Food waste was dried at three temperatures of 55°C, 70°C, and 85°C in three times of 90, 150, and 210 min after the dryer was set up in two conditions of return and non-return flow. The results showed that the quantity of energy spent is decreased to one-third of the non-return state due to the reuse of output energy. Exergy waste will be decreased by up to 11.5 times. Increasing device efficiency and lowering expenses entails decreasing wasted exergy. Furthermore, the modifications in the stability index mean that the amount of pollutants produced by reverse flow will be lower.

Keywords: energy consumption, wasted exergy, stability index, exergy efficiency

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1 Introduction

On the other side, population growth has increased resource consumption for food supply, and a high percentage of food waste in the food supply chain equals resource waste (Godfray et al., 2010; Pretty et al., 2005). As a result, an integrated and comprehensive food management approach is required (Dou et al., 2018). According to reports, the world wastes 1.6 billion tons of food each year, resulting in 3.3 billion tons of CO2 (Food and Agriculture Organization, 2013). Food waste has other dimensions than environmental effects, such as wasting economic resources and causing social difficulties (Garcia-Garcia et al., 2017). As a result, waste management using these three methods is critical.

The impacts of food waste on three aspects of the environment (greenhouse gas emissions, natural resource depletion, and resource pollution), the economy (production waste, processing, packing, transportation, and storage expenses), and society

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(where increasing the production of food waste equals risk of reduced Food security) is becoming increasingly crucial for management methods. According to research, the first technique, sustainable food production and opposition to surplus production, has more favorable effects on surplus reduction. The use of food waste for human consumption and conversion into animal feed has been found in the second place (Papargyropoulou et al., 2014). A study by Fung et al. (2019) looked at the amount of energy and nutrients in food waste from four different sources. The amount of minerals, fatty acids, amino acids, and other nutritional qualities were measured in this study. The waste prepared at the supermarket has a higher nutritional value than waste cooked at the university residential dining hall, municipal waste transfer station, or from a household source, according to their findings. As a result, any of these sources can be employed in pig feed diets as long as the amount of nutrients is kept under control (Fung et al., 2019). Due to its huge volume of important nutrients, food waste offers a lot of promise for animal feed production (Truong et al., 2019). San Martin et al. (2016) also used customized protocols to gather the nutritional value of 1 ton of plant waste and transformed it into animal feed in a specific method. Their findings also demonstrate that it can be employed if the nitrite level is kept under control (San Martin et al., 2016). Food waste as animal feed was also investigated by Chen et al. (2015). Their findings suggest that these wastes could be used as animal feed if the impacts on animals are studied (Chen et al., 2015).

On the other hand, Providing resources for agricultural products, will be one of the major issues in the approaching years (Lotze-Campen et al., 2008). A large portion of arable land is now farmed and utilized for the production of animal feed. And, due to population expansion, it is expected that demand for corn and soybeans would increase by 40% over present supply in the future years (Steinfeld et al., 2006). Meat and dairy production are expected to increase by 60 percent by 2050 (Alexandratos and Bruinsma, 2012).

Beretta et al. (2013) used energy analysis in Switzerland to discover that the food supply chain consumes TJ 165,000 energy per year (domestic production and imports). Animal feed accounts for 79% of it, while plant-based food accounts for 21%. Animal-based products, on the other hand, supply only 27% of the energy in the human diet, even when manufacturing losses are taken into account. Only 52 percent of the energy consumed by the (domestic) agricultural and livestock production industry is for human consumption. Unavoidable waste accounts for 21%, whereas preventable waste accounts for 26%. This waste can be used as animal feed to reduce energy usage for production (Beretta et al., 2013).

In addition to the current energy crisis, future population expansion will increase demand for energy supplies, and because fossil fuels are the world's primary source of energy, there will be additional issues such as climate change and resource scarcity. Reduced food and agricultural products, as well as a lack of drinking water, are all consequences of climate change (Mihajlović and Trajković, 2018).

Food wastes in underdeveloped countries can be a fertile field for reducing hunger and its negative consequences on the environment, as well as raising income and providing jobs (Torres-León et al., 2018). Finally, using millet energy resources to produce animal-based meals lowers production costs.

The goal of this research was to compare energy and exergy for the manufacturing of animal feed from food waste in two distinct ways in order to reduce energy consumption and boost exergy efficiency.

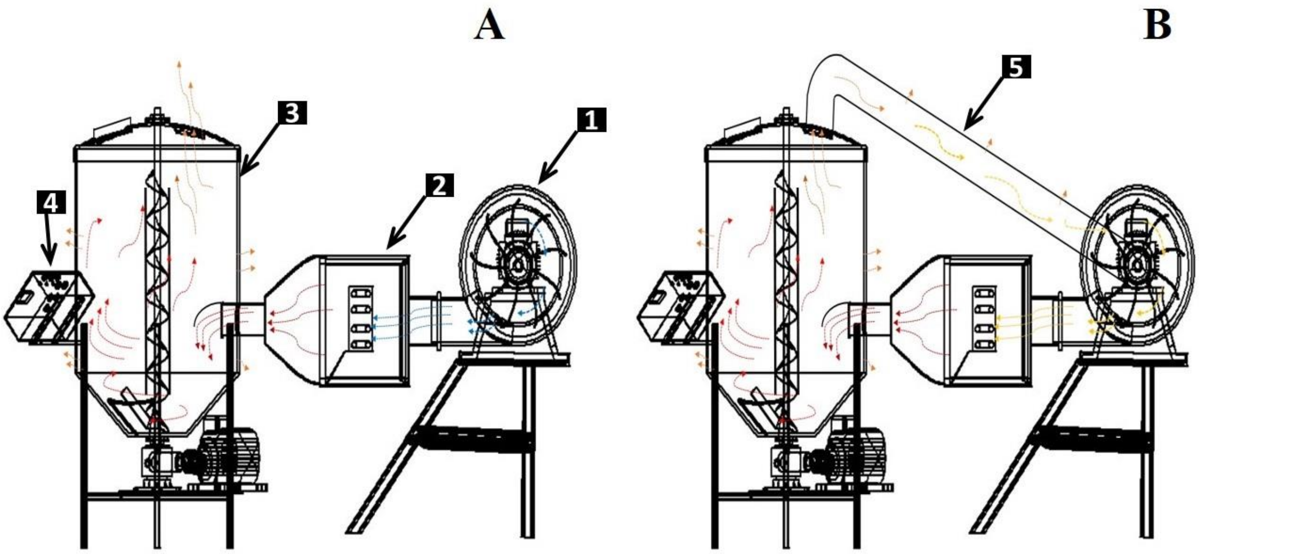
2 Materials and methods

2.1 Sample preparation

The kitchen was used to prepare the requisite food waste. The required sample for testing in all treatments was prepared and tested in one day due to the variance in moisture in food waste. Drying was done at three different temperatures: 55°C, 70°C, and 85°C for 90, 150, and 210 min respectively. On several days, the experiments were repeated. The prepared food waste is poured into the device's tank (Figure 1), the temperature of the controller is set to a certain temperature, and hot air enters the tank with the help of a fan and heater, hot and humid air leaves the tank in a non-return flow, and the fan re-circulates the ambient air in a drying cycle. In the non-return state; however, hot, humid air enters the return air pipe, is mixed with fresh air, and the drying cycle begins. The Ecotec heat controller (model sic38H, dimensions 48 × 96, maid in Iran) was used to regulate the temperature. A HOLDPEAK non-contact thermometer was used to continually measure the intake and outlet temperatures, as well as the cylindrical body, every half hour (model HP-112, made in Hong Kong).

2.2 Introducing the device

The dryer tank, heater, electrical panel, and fan are the four basic components of the device in both return and non-return states. The air return channel is the distinction between these two devices. This channel is installed on top of the dryer cylinder lid, as indicated in Figure 1.



(a) Non-reverse flow (b) Reverse flow

(c) The real figure of the device

1- Centrifugal fan, 2- Heater, 3- Tank, 4- Electrical panel, 5- Air return duct

Figure 1 Schematic of food waste dryer

Table 1 Equations needed to perform the calculations

No.	Parameters	Units	Equations	References
1	Percentage of moisture	%	$W=\frac{Mo-Mi}{Mi}$	(Ergün et al., 2017)
2	Energy consumption	$kj.s^{-1}$	$\times (h_{dai} - h_{dao})\ \dot{m}_{da} = Eu$	(Jiang et al., 2017)
3	Mass flow of air	$kg.s^{-1}$	$\dot{m}_{da} = \rho_a \times 47.2 \times 0.0113$	(Taheri-Garavand et al., 2018)
4	Dry air density	$kg.m^3$	$\rho a = \frac{101.325}{0.287(Ta + 273.16)}$	(Mokhtarian et al., 2016)
5	Enthalpy of the drying air	$J.kg^{-1}$	$h_{da} = C_{pda} \times (T- T_{\infty}) + h_{fg}$	(Topic, 1995)
6	Specific heat capacity	$J.kg^{-1}{}^{\circ}C^{-1}$	$C_{pda} = 1.004 + 1.88 \times w$	(Aghbashlo et al., 2008)
7	Humidity ratio	-	$w = 0.622 \times \frac{\varphi \times P_{vs}}{P - P_{vs}}$	(Nazghelichi et al., 2010)
8	Saturated vapor pressure	kPa	$Pvs = 0.1\exp(\left(27.0214 - \frac{6887}{Ta + 273.16}\right) - 5.31 Ln\left(\frac{Ta + 273.16}{273.16}\right))$	(Mondal et al., 2021)
9	Wasted exergy	$kj.s^{-1}$	$Ex_l = Ex_{ai} - Ex_{ao} - EX_s$	(Aviara et al., 2014)
10	Exergy	$kj.s^{-1}$	$Ex = \dot{m}_{da} \times C_{pda} \times [(T- T_{\infty}) - T_{\infty} \times Ln\frac{T}{T_{\infty}}]$	(Midilli and Kucuk, 2003)
11	Exergy of dryer chamber with the environment	$kj.s^{-1}$	$EXs = (1 - \frac{T\infty}{Ts}) * Q$	(Sarker et al., 2015)
12	Energy dissipated	$kj.s^{-1}$	$Q=\frac{2\pi L(Ti-Ts)}{(\ln(\frac{r2}{r1})/K1)+(\ln(\frac{r3}{r2})/K2)+(\ln(\frac{r4}{r3})/K3)}$	(Dewitt et al., 2012)
13	Energy efficiency	-	$\eta_{en} = \frac{Eu_i - Eu_o}{Eu_i} = 1 - \frac{Eu_o}{Eu_i}$	(Aviara et al., 2014)
14	Exergy efficiency	-	$\eta_{ex} = \frac{Ex_i - Ex_l}{Ex_i} = 1 - \frac{Ex_l}{Ex_i}$	(Sheikhshoaei et al., 2020)
15	Improvement potential rate	$kj.s^{-1}$	$EIPR=(1-\eta_{en})(Ex_i - Ex_o)$	(Afzali et al., 2019)
16	Sustainability index		$SI=\frac{1}{(1-\eta_{ex})}$	(Afzali et al., 2019)

3 Results and discussion

As demonstrated in Figure 2, energy usage rises as the temperature rises. These findings are comparable to those of Motevali et al. (2012), who used a thin layer dryer to dry jujube. In addition, Minaei et al. (2014) found that increasing the temperature increases the device's energy consumption (Minaei et al., 2014; Motevali et al., 2012). The energy consumption in non-reversible and reversible states is likewise considerably different, as seen in Figure 2. As a result, the energy used in the return state is one-third of the energy used in the non-return state.

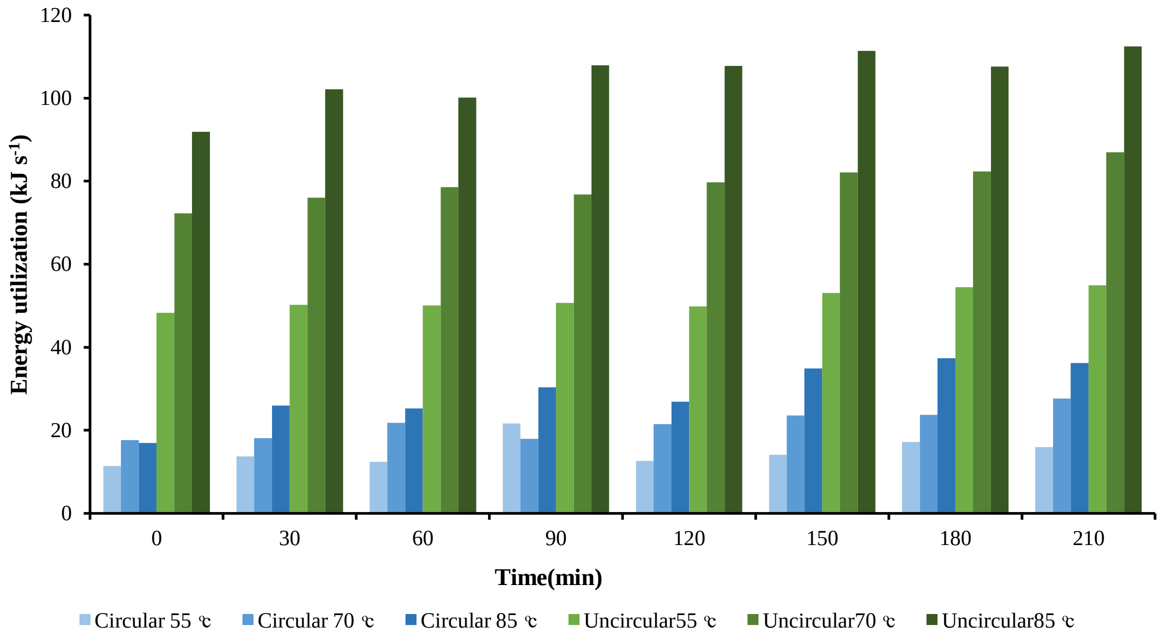


Figure 2 Energy consumption in both return and non-return states

3.1 Energy efficiency

As you can see, energy efficiency improves as the temperature rises. Increased the temperature, in fact, means increasing energy consumption and, as a result, decreasing energy efficiency. Sarker et al. (2015) and Aviara et al. (2014) found comparable results. The energy efficiency for both reversible and non-reversible states is shown in Figure 3.

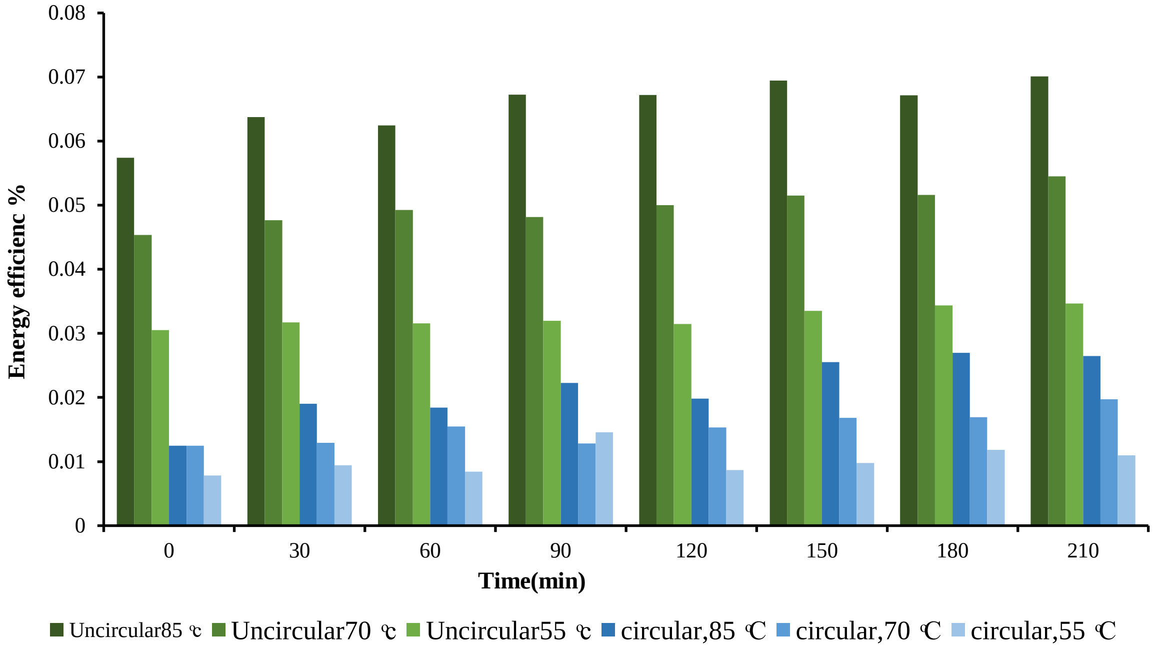


Figure 3 Energy efficiency for both reversible and non-reversible states

3.2 Wasted exergy

The quantity of exergy wasted in the reverse flow mode is substantially less than in the non-return flow mode, as shown in Figure 4. As a result, the total wasted exergy in the reverse current state is around half that of the non-reversible state at 55°C. In addition, as the temperature rose, the average amount of energy lost rose as well. The computed values are similar to those obtained in the drying process by Corzo et al. (2008), Khanali et al. (2013), and Yogendrasasidhar and Setty (2018).

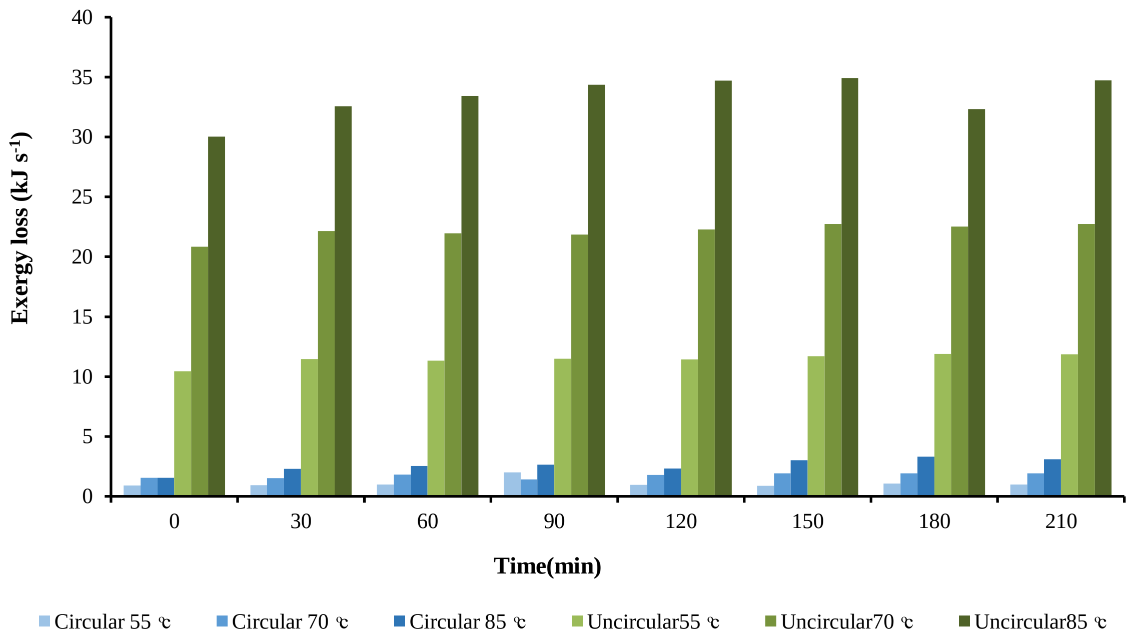


Figure 4 Exergy wasted in reverse and non-reverse flow states

3.3 Exergy efficiency

Exergy efficiency decreases as wasted exergy rises. Exergy efficiency declines with rising temperature, as shown in Figure 5. In addition, the efficiency of reverse and non-reverse flow states differs significantly.

The results reported in this investigation for food waste are similar to those obtained in previous studies for slicing carrots, millet seeds, and rough rice (Aghbashlo et al., 2009; Khanali et al., 2013; Yogendrasasidhar and Setty, 2018).

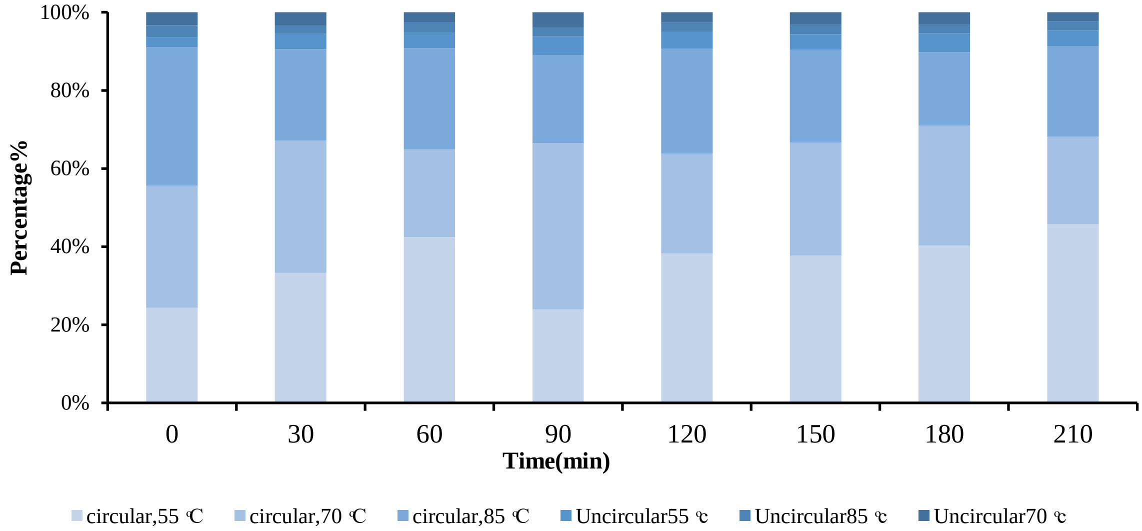


Figure 5 Exergy efficiency of dryer in return and non-return states

3.4 Improvement potential ratio

The recovery potential ratio is directly affected by exergy efficiency and wasted exergy. As a result of the reduced exergy efficiency, the healing potential rises. As illustrated in Figure 6, in the non-reversible state, has a substantially higher recovery potential than the reversible state, with the reversible state's overall recovery potential being roughly one-third that of the non-reversible state at 55°C.

Similar to the calculated data, Aviara et al. (2014) stated that when temperature rises, the potential for improvement rises as well. In the process of drying apple slices, the potential for exergy recovery rises as well (Aviara et al., 2014; Ghasemkhani et al., 2016).

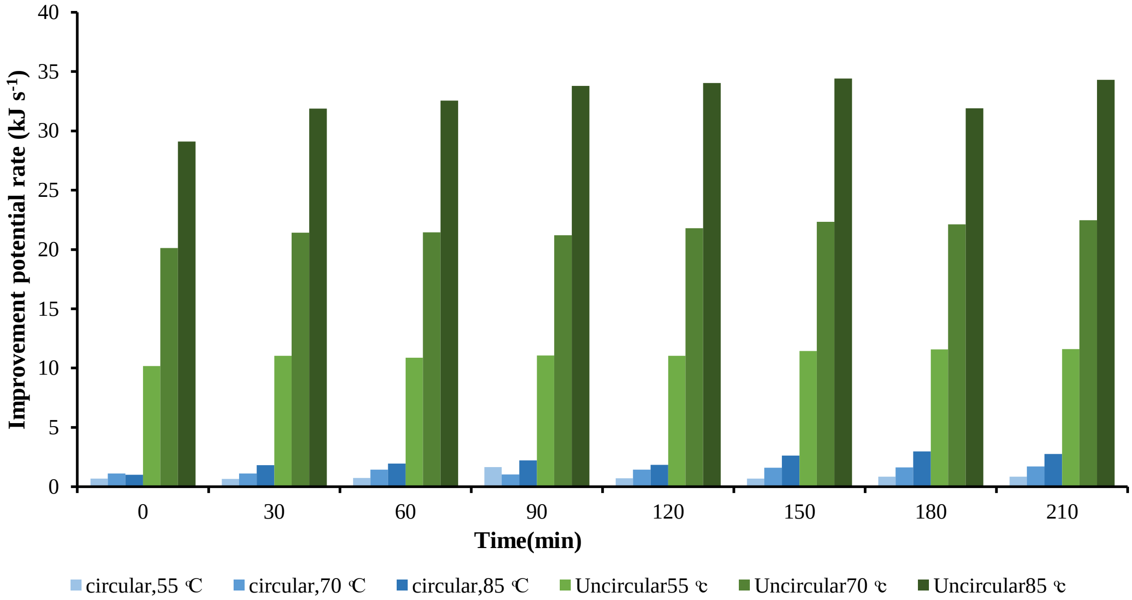


Figure 6 Potential for recovery in non-reversible and reversible states

3.5 Sustainability index

The stability index reduces with increasing temperature, as shown in Figure 7. Hence, in addition to temperature, is being in the non-return can an impact on the stability index, resulting in a rapid reduction in the value of the stable index. This could be due to the device's exergy efficiency being reduced. Increasing greenhouse gas emissions imply decreasing the stability index (Rosen et al., 2008), thus we should aim to improve energy efficiency.

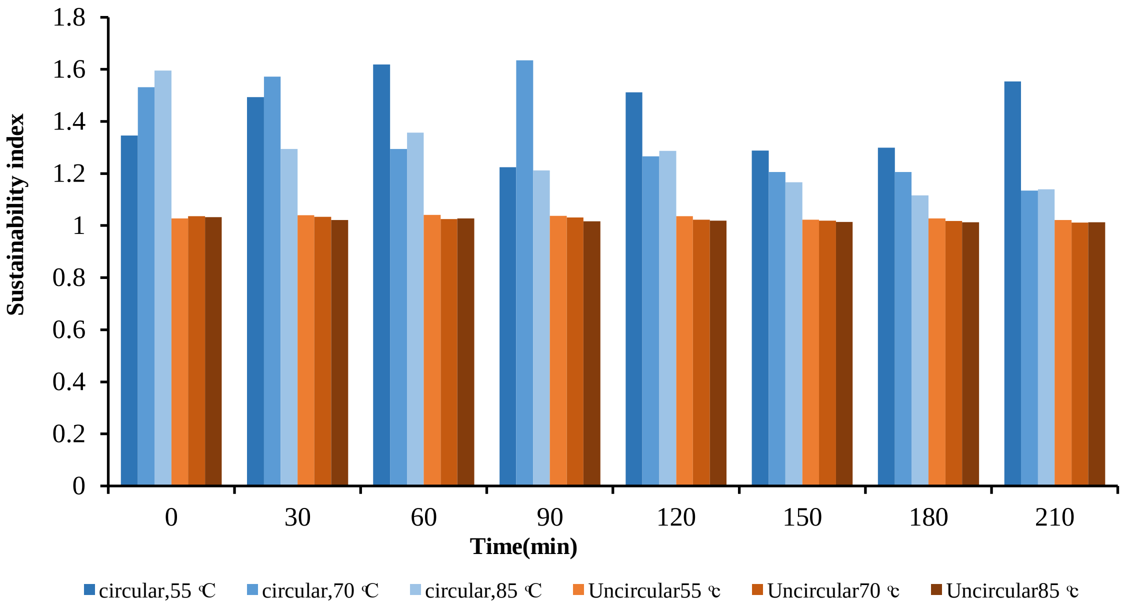


Figure 7 Stability index in both reversible and non-reversible states

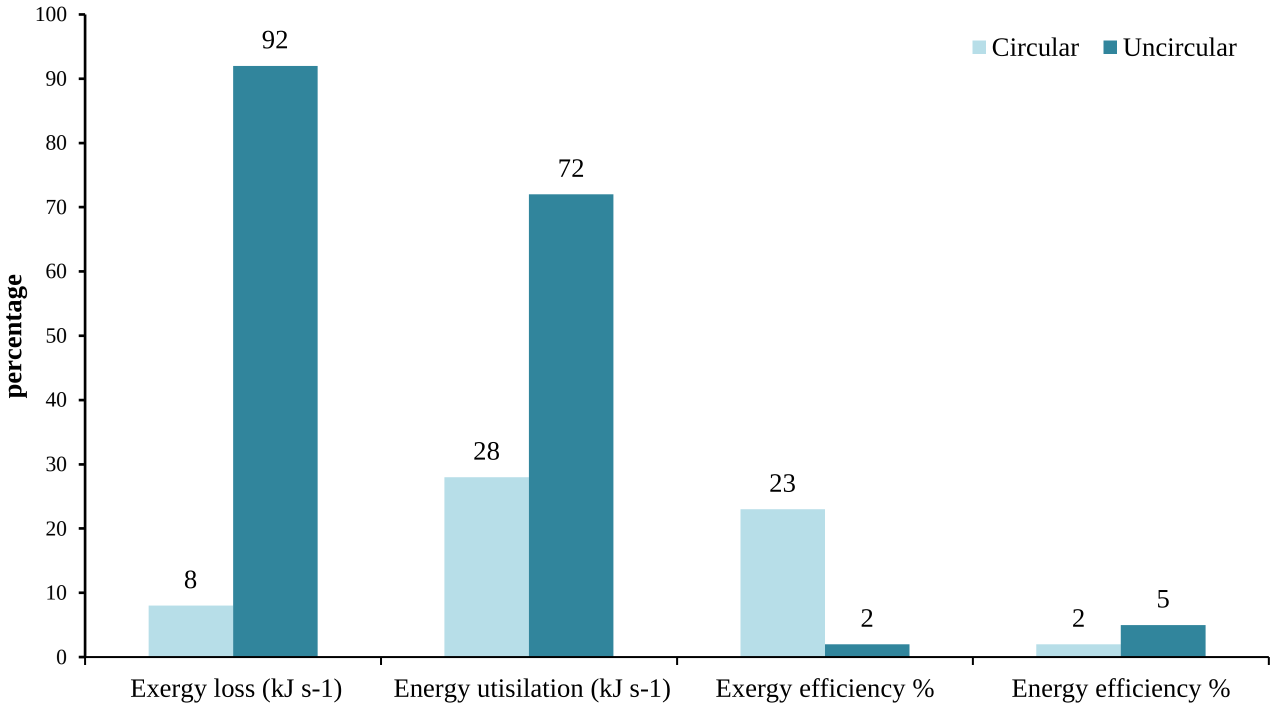


Figure 8 Energy efficiency, exergy efficiency, percentage of average energy consumption and wasted exergy

3.6 Final comparison between return and non-return current

Figure 8 shows that the average energy efficiency for the non-reversible mode is 5%, but only 2% for the reversible mode, implying that the non-reversible mode consumes 2.5 times more energy. The exergy efficiency, on the other hand, declined to 2% in the non-reversible condition and jumped to 23% in the reversible state. Exergy efficiency refers to the amount of energy lost during the drying process.

The average energy consumed in reverse mode at three different temperatures was 21.872 kJ s^{-1}. If only at 70°C in the non-reversible mode, an average of 79.347 kJ h^{-1} was consumed, in the end this is equal to 28% of the average energy Consumption at three different temperatures is in the non-reversible.

At three temperatures, the average exergy wasted was 1.806 kJ s^{-1} for return mode and 22.321 kJ s^{-1} for non-return mode. The wasted exergy in the reversible state is 8% of the wasted exergy in the non-reversible state, as shown in Figure 8.

4 Conclusion

Different waste management strategies have different advantages and disadvantages. One of the beneficial and developing techniques to waste management has been the production of animal feed from food waste. Energy consumption and exergy of a food waste dryer were studied in this study and it was found that by reusing the energy required to dry food waste, the amount of energy consumed may be reduced by half. It will also reduce energy efficiency. The energy lost as a result of energy reuse is greatly reduced. Findings indicate that by installing an exhaust air return system, the amount of exhaust exergy can be reduced up to 11.5 times. Reducing the energy wasted in the device leads to an increase in performance.

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