

EVALUATION OF GGE OF DIFFERENT PROCESS FOR DRYING ORANGE SLICES

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Abstract

Just because of burning fossil fuels and the fact that renewable energy sources (solar, wind, hydraulic, geothermal, biomass, tidal, wave etc.) have not become widespread globally, many parallel environmental problems such as global warming, climate change and carbon emissions have been emerged. In the present study, two different orange cultivars (Valencia and Washington Navel) were dried under different air-convective conditions (50, 55 and 60°C). Samples were sliced three different thickness as 5, 7 and 9 mm, respectively. In addition, three different drying time was selected for orange drying as 8, 9 and 10 h, respectively. The effects of a single unit air convective drying of 1 kg product on greenhouse gas emissions (GGE) of different types of power plants (wind, solar, hydroelectric, and geothermal) were investigated. Present findings revealed that while the greatest GGE were obtained from the geothermal power plant, the lowest values were obtained from the wind power plant. Besides, increasing CO₂ emissions were encountered with increasing drying time and sample thickness. Additionally, CO₂ emissions had a decreasing trend at higher temperatures.

Keywords: Drying, emission, optimization, orange, slice thickness

1. INTRODUCTION

Orange (*Citrus sinensis* L.) is one of the most consumed fruits in the world (Farahmandfar et al., 2019). World total production of major citrus products is 143.5 million tons, of which 54.85% is constituted by orange, 24.70% by tangerine, 13.97% by lemon and 6.47% by grapefruit (FAO, 2021). Drying methods is important for removal of excess moisture and also air convective method is most widely used ones (Çetin and Sağlam, 2022; Çetin and Sağlam, 2022). However, energy consumption is high in these drying systems due to the lack of optimization (Sahin and Dincer, 2002).

Drying processes has various thermal energy functions and intensive processes requiring high energy consumptions (Barati and Esfahani, 2010). The most important cost in these systems is electrical energy. Additionally, greenhouse gas emissions (GGE) and environment-related impacts are significant problems to be considered (Kaveh et al., 2020).

Climate change is largely triggered by power plant emissions. Burning fossil fuels release smoke, thus greenhouse gases into the atmosphere. Such greenhouse gas emissions of fossil fuel-burning power plants and vehicles ultimately exacerbate various problems including climate change, global warming, floods, desertification, acid rains, depletion of ozone layer, sea level rises and the other

environmental problems. All these problems ultimately influence human life (Kaveh et al., 2020). The primary sectors contributing to CO₂ emissions include respectively the energy sector with 42% contribution, the transportation sector with 23% contribution and the industrial sector with 18% contribution (IEA, 2015).

Response surface methodology (RSM) is a statistical procedure used for optimization of multivariate problems. RSM reveals the relationships between one or more measured response and multiple input variables. RSM may also offer reliable statistical outcomes with a smaller number of trials (Kaur et al., 2009).

Present literature reviews revealed that optimization of operational drying conditions, especially in terms of greenhouse gas emissions of drying of orange slices has not been studied at all. Therefore, in this study, the effects of air convective drying of orange slices on greenhouse gas emissions of different types of power plants (wind, solar, hydroelectric, and geothermal) were investigated.

2. MATERIALS AND METHODS

Two commonly cultivated orange (*Citrus sinensis* L.) cultivars ('Washington Navel' and 'Valencia') were used as the material. Drying processes were carried out in a single unit convective drying cabinet (ETHK-20M, TR). A single unit air-convective drying cabinet was presented in Figure 1.

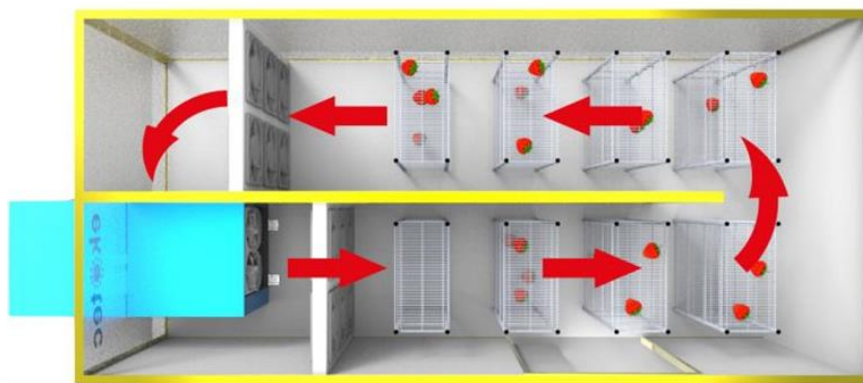


Figure 1. A single unit air convective dryer

In this study, response surface methodology was applied for the drying conditions. Box–Behnken design was used with different drying temperature (50-60°C), sample thickness (5-9 mm) and drying time (8-10 h) being the independent process variables (Table 1).

The energy required by different dryers can be determined using the total energy equation. Power plants supply this electric energy through distribution networks. The energy generated by the power plants is partially lost as a heat energy in networks and sub-stations. Such losses should be taken into consideration while calculating the energy required to generate 1 kW electricity production. Losses in networks and transformer centers are around 14.2%. In addition, the average internal consumption of the power plants is approximately 3.5% (IEA, Turkey Energy Balance Sheet 2015).

Table 1. Independent variables and their levels in the Box–Behnken design.

Independent variables	Unit	Symbol	Level 1 Low, (-1)	Level 2 Mid, (0)	Level 3 High, (1)
Temperature	°C	T	50	55	60
Sample thickness	mm	ST	5	7	9
Drying time	h	DT	8	9	10
Box–Behnken design					
Run	Temperature		Sample thickness	Drying time	
1	50		5	9	
2	50		7	8	
3	50		7	10	
4	50		9	9	
5	55		9	10	
6	55		5	8	
7	55		7	9	
8	55		7	9	
9	55		7	9	
10	55		9	8	
11	55		5	10	
12	60		7	8	
13	60		7	10	
14	60		5	9	
15	60		9	9	

The following equation is used to calculate the total energy to be generated by a power plant for drying operations (Motevali and Kolor, 2017).

$$Total\ Energy = \frac{SEC}{\eta_{total}} = \frac{SEC}{\eta_{powerhouse} + \eta_{distribution}} \quad (1)$$

where;

SEC = Specific energy consumption (kW/kg)

η_{total} = Total efficiency (%)

$\eta_{powerhouse}$ = Power house efficiency (%)

$\eta_{distribution}$ = Distribution efficiency (%)

Greenhouse gas emissions (GGE) per kg of electricity production for different plants were calculated by using greenhouse gas production factors specified in Sovacool (2008). In present study, indirect method was employed to get GGE based on electrical energy consumption of drying. The energy produced by power plants to remove 1 kg moisture from the orange slices was determined initially with the use of energy needs of experimental processes. Following the determination of energy requirements of the experimental processes and pre-treatments of the

drying system (thermal and mechanical), the electrical transmission factor from the power plant to the consumption point was selected. The internal consumption factor was utilized to identify total electricity production. Then, pollutant emissions per 1 kWh of electricity consumption were calculated. Turkey is one of the countries with large greenhouse gas emissions and power plants are generally composed of wind, solar, hydroelectric and geothermal types, and the average greenhouse gas emission values of these sources in electricity generation systems are 10, 23, 26 and 38 gCO₂e kWh⁻¹, respectively (Melikoglu 2013; Sovacool 2008). Therefore, these values were taken into account in GGE estimations.

In the present study, a 3-level factorial experimental design with 3 replicates at the center point was used to develop predictive models (Box & Behnken, 1960; Karaman et al., 2016; Karaman and Sagdic, 2019). The three factors were used as temperature, sample thickness and drying time. The experimental design was created by using Design-Expert® Software Version 7.0 (Stat-Ease Inc., Minneapolis, USA).

3. RESULTS AND DISCUSSIONS

The greatest and the lowest GGE of different conditions and power plants to dry 1 kg orange are provided in Table 2 and 3. Considering entire power plants and orange cultivars, the greatest CO₂ emission was encountered in the 14th run. Increasing CO₂ emissions were seen with increasing drying durations and slice thicknesses. These GGE followed a decreasing trend at higher temperatures due to lower energy consumption at higher temperatures. Convective drying, commonly used in drying various agricultural products, with lower energy and drying efficiency requires longer drying durations. Accordingly, it can be resulted that convective drying had a large share in world greenhouse gas emissions (Motevali et al., 2014). When the results of different power plants such as wind, solar, hydroelectric, and geothermal were analyzed, it was seen that wind power plants yielded significantly lower greenhouse gas emissions than the other power plants. Although microwave, convective and vacuum dryers have high efficiencies, they may yield greater greenhouse gas emissions than the convective dryers. Convective dryers, when combined with the drying techniques such as infrared and microwave, can result in better efficiencies and less greenhouse gas emissions (Motevali et al., 2014). Similar with the present findings, Motevali and Kolor (2017) dried dogrose in a convective dryer at 40, 50 and 60°C temperatures and reported CO₂ emissions as between 6539.17 g kg⁻¹ and 16419.18 g kg⁻¹ for combined cycle power plant and between 915.48 g kg⁻¹ and 27057.32.18 g kg⁻¹ for steam power plant. Kaveh et al. (2020) dried *Pistacia atlantica* samples in convective dryer at 40, 55 and 70°C drying temperatures and reported the lowest emissions for 70°C and the greatest for 40°C. Increasing greenhouse gas emissions yielded greater SEC values at low temperatures.

Table 2. GGE of wind and solar powerplants for one kg of crop ($g\ kg^{-1}$)

Run	Wind		Solar	
	Valencia	Washington	Valencia	Washington
1	2069.41	1839.94	4759.65	4231.87
2	1421.64	1517.13	3269.78	3489.39
3	1534.20	1634.04	3528.67	3758.28
4	1580.67	1370.33	3635.54	3151.76
5	2311.77	1604.56	5317.08	3690.49
6	2272.20	2260.71	5226.06	5199.62
7	1808.09	1958.50	4158.60	4504.54
8	2069.82	1479.36	4760.59	3402.53
9	2256.52	1611.54	5189.99	3706.54
10	1664.33	1248.49	3827.96	2871.54
11	2490.42	2595.02	5727.97	5968.54
12	1673.53	1538.96	3849.11	3539.62
13	2160.63	1803.74	4969.44	4148.60
14	2773.42	2735.00	6378.87	6290.49
15	1862.03	1601.44	4282.66	3683.32

Table 3. GGE of hydroelectric and geothermal powerplants for one kg of crop ($g\ kg^{-1}$)

Run	Hydroelectric		Geothermal	
	Valencia	Washington	Valencia	Washington
1	5380.47	4783.85	7863.77	6991.78
2	3696.27	3944.53	5402.25	5765.08
3	3988.93	4248.49	5829.97	6209.34
4	4109.75	3562.86	6006.55	5207.26
5	6010.61	4171.86	8784.73	6097.34
6	5907.72	5877.83	8634.36	8590.68
7	4701.03	5092.09	6870.74	7442.28
8	5381.54	3846.34	7865.33	5621.57
9	5866.95	4190.01	8574.77	6123.86
10	4327.26	3246.09	6324.46	4744.28
11	6475.10	6747.04	9463.60	9861.06
12	4351.17	4001.31	6359.40	5848.07
13	5617.63	4689.72	8210.38	6854.20
14	7210.89	7110.99	10539.00	10392.99
15	4841.27	4163.75	7075.71	6085.48

4. CONCLUSIONS

Two orange cultivars were subjected to drying processes with the use of air-convective drying method. Experiments were conducted at 50, 55 and 60°C drying air temperatures, 5, 7 and 9 mm slice thicknesses and 8, 9 and 10 h drying times in Box–Behnken design and RSM by using desirability function. Greenhouse gas emissions for 1 kg electric energy production of different types of power plants were also investigated in this study. Increasing CO₂ emissions were encountered with increasing drying time and sample thicknesses. Besides, these emissions had decreasing trends at higher temperatures. Increase in greenhouse gas emissions could be explained by higher SEC values at lower drying air temperature.

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