Journal of Oleo Science
Copyright ©2018 by Japan Oil Chemists' Society
doi : 10.5650/jos.ess17134
J. Oleo Sci. **67**, *(1) 21-28 (2018)*

Multi-objective Optimization of Molecular Distillation Conditions for Oleic Acid from a Rich-in-Fatty Acid Model Mixture

Onur KETENOĞLU[1], Ferruh ERDOĞDU[2] and Aziz TEKİN[2]*

[1] *Department of Food Engineering, Cankiri Karatekin University, TURKEY*
[2] *Department of Food Engineering, Ankara University, TURKEY*

Abstract: Oleic acid is a commercially valuable compound and has many positive health effects. Determining optimum conditions in a physical separation process is an industrially significant point due to environmental and health related concerns. Molecular distillation avoids the use of chemicals and adverse effects of high temperature application. The objective of this study was to determine the molecular distillation conditions for oleic acid to increase its purity and distillation yield in a model fatty acid mixture. For this purpose, a short-path evaporator column was used. Evaporation temperature ranged from 110 to 190℃, while absolute pressure was from 0.05 to 5 mmHg. Results showed that elevating temperature generally increased distillation yield until a maximum evaporation temperature. Vacuum application also affected the yield at a given temperature, and amount of distillate increased at higher vacuums except the case applied at 190℃. A multi-objective optimization procedure was then used for maximizing both yield and oleic acid amounts in distillate simultaneously, and an optimum point of 177.36℃ and 0.051 mmHg was determined for this purpose. Results also demonstrated that evaporation of oleic acid was also suppressed by a secondary dominant fatty acid of olive oil – palmitic acid, which tended to evaporate easier than oleic acid at lower evaporation temperatures, and increasing temperature achieved to transfer more oleic acid to distillate. At 110℃ and 0.05 mmHg, oleic and palmitic acid concentrations in distillate were 63.67% and 24.32%, respectively. Outcomes of this study are expected to be useful for industrial process conditions.

Key words: oleic acid, molecular distillation, multi-objective optimization, extraction, olive oil, vapor pressure

1 Introduction

Oleic acid (cis-9-octadecenoic acid, (C18:1)) is the main part of fatty acids (FA) of olive oil and a member of mono-unsaturated fatty acids. It is naturally present in human diet via a wide range of vegetable oils. Besides, there are numerous applications and uses of oleic acid industrially. Some uses of oleic acid include areas like cosmetics, additives in food products, lubricants[1)] and emulsion formation[2)].

Olive oil contains about 55-83% of oleic acid. This composition is affected by such factors like climate, moisture content of fruit and geographical location[3)]. However, there are also a number of vegetable oils rich in oleic acid; such as hazelnut oil (74-80%), almond oil (65-70%)[4)], peanut oil (46.7%)[3)], sunflower oil -regular: 20-30%[4)], hi-oleic: 81.3%[3)].

Besides the variety of its industrial use, oleic acid is well-known for its positive effects on human health due to its mono-unsaturated structure, such as decreasing cardiovascular diseases, blood pressure and also low-density lipoproteins (LDL)[5, 6)]. Oleic acid rich diets were also reported to have a relation with decreased levels of inflammatory diseases[7)]. As a main source of oleic acid, there are also some studies against the strong belief of relation between olive oil consumption and obesity[8)]. As a result of all these benefits and uses in industry, purification of oleic acid and enrichment in human diet are of great importance. Currently, it is produced by chemical techniques[1)]. Physical separation of oleic acid from natural sources have been gaining more interest, however there are limited studies involving in physical separation of this valuable compound due to insufficient evaporation equilibrium data. In a study about biodiesel fuels, Yuan *et al.*[9)] pointed a correlation between experimental and reported data of various pure fatty acid

*Correspondence to: Aziz TEKİN, Department of Food Engineering, Ankara University, TURKEY
E-mail: tekin@ankara.edu.tr,
Accepted August 21, 2017 (received for review June 15, 2017)
Journal of Oleo Science ISSN 1345-8957 print / ISSN 1347-3352 online
http://www.jstage.jst.go.jp/browse/jos/ http://mc.manusriptcentral.com/jjocs

methyl esters. They predicted normal boiling point of oleic acid using Antoine equation, and reported that oleic acid methyl ester had a predicted normal boiling point of 622 K which is in a good correlation with the reference data. In another study involving vapor-liquid equilibrium of fatty systems, it was achieved to develop a group of contribution methods with including molecular weight as a parameter for vapor-liquid equilibrium behavior of various fatty acids and their ester forms[10].

Due to the recent environmental and health related concerns, use of chemical techniques is not preferred for the purification of oleic acid. Molecular distillation avoids the use of organic solvents, and it prevents the adverse effects of high temperature application. Besides, it is capable of directly focusing on purification of a single compound. Therefore, the objective of this study was to optimize molecular distillation conditions of oleic acid and observe the evaporation behavior under different temperatures and pressures. In addition to various studies dealing with empirical approaches and predictions, outcomes of this experimental research are expected to be useful for industrial production.

2 Experimental

2.1 Materials

Olive oil was purchased from a local supermarket. Potassium hydroxide, ethanol, hexane, acetic acid and anhydrous sodium sulfate were purchased from Sigma-Aldrich (Steinheim, Germany). All reagents were of analytical grade. Oily materials were stored at 4℃ and kept in dark to avoid oxidation.

2.2 Fatty acid production

Olive oil was saponified with KOH using ethanol as catalyst. After removing unsaponified compounds by hexane, acid oil (AO) was produced by introducing a calculated amount of acetic acid into the saponified part. AO was then treated with Na_2SO_4 to remove water.

2.3 Free fatty acid (FFA) analysis

FFAs were determined according to AOCS Official Method Ca 5a-40[11]. All results were given in terms of % oleic acid.

2.4 Gas chromatography (GC) analysis

FFAs were converted to their methyl esters according to method suggested by Hammond and Wang[12] with slight modifications. The esters were injected into GC-2010 gas chromatography (Shimadzu, Japan) through a 30 m DB-23 capillary column (Agilent, CA, USA). Helium was the carrier and a method with 230℃ injection block temperature, 190℃ column temperature, 240℃ flame ionization detector (FID) temperature, 1 μL injection volume and 0.3 mL min^{-1} column flow was used.

2.5 Molecular distillation experiments

Molecular distillation steps were carried out by using a laboratory scale wiped film short-path evaporator, model KDL5 (UiC GmbH, Alzenau, Germany). Evaporation surface area was 0.05 m^2, condenser temperature was set to 20℃, wiper speed was 240 rpm and feed flow was adjusted to 3 mL min^{-1}. AO was initially distilled under 0.05 mmHg at 200℃ to remove impurities and increase its acidity to 100%. This mixture is called as distilled oil phase (DAO) and further distillations were carried out using DAO at 110, 130, 150, 170 and 190℃ under 0.05, 0.5 and 5 mmHg absolute pressures.

2.6 Optimization

Experimental data were analyzed to evaluate the effects of temperature and pressure on distillate stream yields and oleic acid amounts in the distillate. Pressure values were transformed into logarithmic scale for linearization, and experimental data were fitted to quadratic equations using Statistica v10 (Statsoft, Tulsa, OK).

In literature, the optimization methods could be divided into groups, one of which is the "multi-objective optimization" (also known as "Pareto optimization"). Multi-objective optimization method focuses on optimizing more than one objective functions simultaneously[13, 14] and there are various usage areas of multi-objective optimization in science[13]. A multi-objective optimization procedure for the given quadratic equations was then performed with ModeFrontier v4.6 (Esteco, Trieste, Italy). The objective of this multi-objective constrained optimization study was to maximize the distillate yield and the oleic acid in the distilled samples simultaneously. For this purpose, the given objective functions for yield and oleic acid were combined into a scalar objective function using the arbitrary weight factors. The explicit constraints on the individual objective functions were decided based on the initial optimization runs. This approach enabled a computationally tractable optimization problem.

Objective functions, explicit-implicit variables and constrains were as follows:

The objective functions:

$$75 < \mathrm{Max}(\text{Oleic acid}) = f_{\text{Oleic}}(P,T) < 100 \quad (1)$$

$$0 < \mathrm{Max}(\text{Yield}) = f_{\text{Yield}}(P,T) < 100 \quad (2)$$

Eqs. (1) and (2) were combined into a scalar objective function using arbitrary weight factors (w_1 and w_2). The arbitrary weight factors were defined in pre-optimization studies to enable that $w_1 + w_2 = 1$ and their values were decided to determine their sensitivity for the optimal points.

$$Max(w_1.[f_{Oleic}(P,T)] + w_2.[f_{Yield}(P,T)]) \quad (3)$$

Explicit constrains for P, T:

$$0.05 \le P \le 5 \text{ in mmHg} \quad \text{and} \quad 110 \le T \le 190 \text{ in℃} \quad (4)$$

To determine the optimum condition, simplex method was used as heuristic optimizer method with maximum number of design evaluations of 500, final termination accuracy of 1E-5 and 25 number of designs initially.

3 Results and Discussion

Oleic acid is reported to have a normal boiling point of 360℃ [15]. Raising temperature up to such high values always becomes risky especially for oily materials whether there is an applied vacuum or not. Hence, lowering the temperature with the related pressure should always be the first approach for this purpose. Therefore, molecular distillation application was chosen to be a suitable approach to study for distillation of oleic acid at temperatures below 360℃ to obtain the highest purity of distillate as possible.

FFA of DAO was found to be 100%, which is expected as it should be to properly start the experiments without any impurities. Table 1 shows the FFA contents and fatty acid compositions of olive oil, AO and DAO and there were almost no significant changes in their fatty acid compositions.

During distillation, increasing temperature resulted in higher amounts of distillates until an optimum temperature level was reached when all other parameters like feed rate, feed temperature and wiper speed were kept constant. On the other hand, the risk of thermal decomposition increases with elevating temperature. An optimum P-T point was therefore aimed to determine and optimize to increase the yield and oleic acid of distillate. In distillation, the ratio of the distillate to residue is defined to be the split ratio value (Eq. 5c).

$$Distillate(\%) = \frac{m_{distillate}}{m_{distillate} + m_{residue}} \quad (5a)$$

$$Residue(\%) = \frac{m_{residue}}{m_{distillate} + m_{residue}} \quad (5b)$$

Table 1 FFA contents and fatty acid composition of olive oil, AO and DAO(%).

	Olive Oil	AO	DAO
FFA	0.74	93.87	100
C16:0	12.90	12.43	12.46
C16:1	0.64	0.54	0.60
C17:0	0.07	0.09	0.08
C17:1	0.12	0.11	0.13
C18:0	2.49	2.46	2.33
C18:1	72.14	75.03	74.96
C18:2	11.09	8.91	8.93
C18:3	0.55	0.44	0.52

Table 2 P-T relations and split ratios of trials.

Temperature (℃)	Pressure (mmHg)	Distillate (%)	Residue (%)	Split Ratio
110	0.05	5.21	94.79	0.05
	0.5	0.00	100.00	0.00
	5	0.00	100.00	0.00
130	0.05	47.88	52.12	0.92
	0.5	6.21	93.79	0.07
	5	0.00	100.00	0.00
150	0.05	88.96	11.04	9.90
	0.5	43.68	56.32	0.78
	5	18.30	81.70	0.23
170	0.05	88.66	11.34	8.26
	0.5	86.78	13.22	6.80
	5	50.19	49.81	1.02
190	0.05	89.98	10.02	9.73
	0.5	91.84	8.16	11.32
	5	88.79	11.21	7.94

$$Split\ Ratio(\%) = \frac{Distillate(\%)}{Residue(\%)} \quad (5c)$$

Increasing the split ratio hence leads to the increase in the distillate yield and/or the decrease in the residue. P-T relations and split ratios for each trial were reported in Table 2. No distillate streams were collected at both 0.5 and 5 mmHg at 110℃ due to insufficient latent heat gain for one evaporation-condensation cycle. However, very little distillate (5.21%) was obtained when 0.05 mmHg vacuum was applied at same temperature. Increasing vacuum at elevated temperatures other than 190℃ also increased the amounts of distillate streams.

Distillate yields at 150℃ - 0.05 mmHg, 170℃-0.05 mmHg and 170℃-0.5 mmHg were similar to the distillate yields at 190℃. However, each trial performed at 190℃ would lead to a higher risk of thermal decomposition and degradation than the other applied temperatures. It was also observed that amounts of distillate stream were not dependent on pressure at 190℃ anymore. Because, as shown in Table 2 and Fig. 1, almost same amounts of distillate streams were collected under all pressures at 190℃.

Fatty acid compositions for all distillation trials were given in Table 3. FAs except the oleic and palmitic acids, which are the main fatty acids of olive oil, had no significant changes during distillation. These two FAs had an inverse relation; one of them increased, while the other one decreased simultaneously. This relation for residual stream could be clearly seen in Fig. 2. This fluctuation can be explained by the lower vapor pressure of palmitic acid compared to oleic acid at the same temperature. According to National Center for Biotechnology Information database, vapor pressure of palmitic acid (PubChem CID:985) at 25℃ is 3.8E-7 mmHg[16] while oleic acid (PubChem CID:445639) has a vapor pressure of 5.46E-7 mmHg at the same temperature[15]. In other words, evaporation temperature of palmitic acid is lower than oleic acid under the same pressure due to its shorter carbon chain structure. This was the main reason for having higher palmitic acid and lower oleic acid in distillate stream at low distillation temperatures. Amount of oleic acid in distillate stream started to elevate when evaporation temperature reached to evaporation range of oleic acid. According to Fig. 3, 74.96% of initial oleic acid in DAO increased to more than 80% after distillations at 130℃-0.05 mmHg, 150℃-0.5 mmHg and 170℃-5 mmHg in residual stream. At these conditions, oleic acid had insufficient latent heat to evaporate and could not be transferred to distillate stream effectively. The percentage of oleic acid in distillate stream was 69.66%, 69.74% and 71.72% at these conditions, respectively. Similarly, distillate streams contained approximately 24% of palmitic acid at low temperatures, such as 110 and 130℃. At higher temperatures, palmitic acid concentrations in distillate streams were about 12%. According to these results, it could be stated that evaporation of oleic acid was suppressed by palmitic acid at lower temperatures, however further temperature increment achieved to increase oleic acid concentration in distillate. When the mixture was distilled at 190℃, any significant effect of applied vacuum was no longer observed. During all distillations, sum of palmitic and oleic acid amounts remained constant at approximately 85-87%.

Table 4 indicates amounts of distillate and residual streams and their oleic acid contents. Increasing distillation temperature and vacuum resulted in collecting more oleic acid (up to 46.04 g) in distillate stream. The sum of oleic acid amounts of distillate and residual streams were found in the range of 48.69-51.94 g, which meant no significant variations from an average of 50 g. The results also showed that, the highest oleic acid concentrations up to 80% (residual stream after distillations at 130℃-0.05 mmHg, 150℃-0.5 mmHg and 170℃-5 mmHg) did not mean that more oleic acid could be collected in terms of mass due to lower

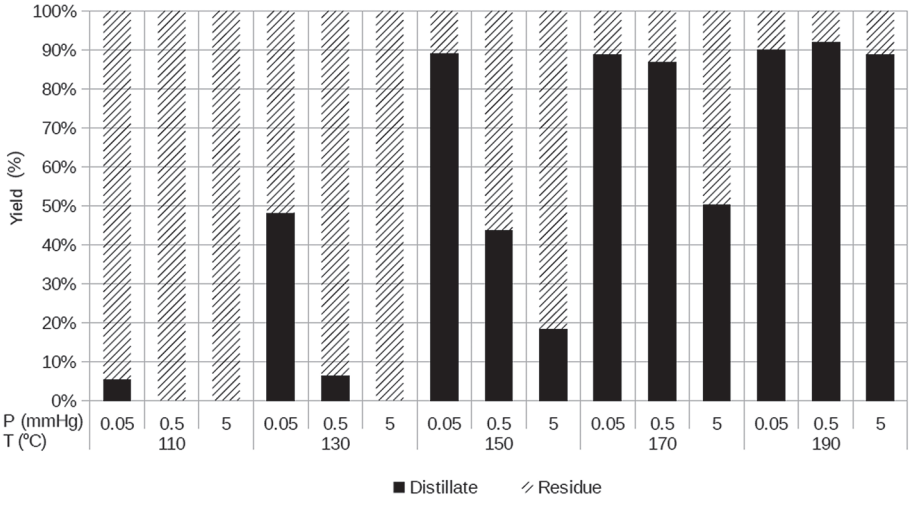


Fig. 1 Yield percentages of distillate and residual streams for each distillation trial.

Table 3 Fatty acid compositions of distilled DAO at various temperatures and pressures (%).

Temperature (℃)	Presure (mmHg)	Stream	C16:0	C16:1	C17:0	C17:1	C18:0	C18:1	C18:2	C18:3
110	0.05	R	10.69	0.49	0.05	0.09	2.53	76.92	8.80	0.44
		D	24.32	1.59	0.08	0.18	1.33	63.67	8.37	0.47
	0.5	R	11.99	0.60	0.07	0.12	2.46	75.43	8.86	0.47
		D	ND	ND	ND	ND	ND	ND	ND	ND
	5	R	12.24	0.54	0.06	0.09	2.42	75.44	8.81	0.41
		D	ND	ND	ND	ND	ND	ND	ND	ND
130	0.05	R	6.10	0.21	0.06	0.09	2.76	81.07	9.21	0.49
		D	18.00	0.95	0.07	0.15	1.81	69.66	8.93	0.43
	0.5	R	11.07	0.49	0.05	0.12	2.46	76.42	8.95	0.45
		D	23.34	1.44	0.08	0.19	1.61	64.59	8.28	0.48
	5	R	12.24	0.53	0.08	0.13	2.35	75.54	8.73	0.41
		D	ND	ND	ND	ND	ND	ND	ND	ND
150	0.05	R	8.71	0.37	0.07	0.10	2.90	78.66	8.76	0.44
		D	12.59	0.62	0.08	0.12	2.20	74.95	8.95	0.49
	0.5	R	6.32	0.20	0.06	0.09	2.70	81.15	9.04	0.45
		D	18.56	0.84	0.08	0.17	1.74	69.74	8.46	0.42
	5	R	9.92	0.40	0.08	0.13	2.39	77.58	9.03	0.48
		D	18.18	0.90	0.08	0.16	1.70	69.94	8.59	0.45
170	0.05	R	13.87	0.75	0.10	0.15	2.36	73.80	8.53	0.44
		D	12.00	0.53	0.09	0.13	2.01	75.82	8.97	0.45
	0.5	R	10.25	0.43	0.11	0.15	2.56	77.43	8.63	0.45
		D	12.37	0.62	0.09	0.14	2.15	75.09	9.02	0.51
	5	R	6.75	0.25	0.08	0.09	2.77	80.48	9.08	0.50
		D	15.97	0.78	0.08	0.15	1.96	71.72	8.88	0.46
190	0.05	R	11.02	0.53	0.08	0.12	2.49	76.28	9.00	0.48
		D	12.40	0.57	0.08	0.13	2.14	75.35	8.85	0.48
	0.5	R	12.57	0.59	0.08	0.14	2.29	75.02	8.89	0.42
		D	12.63	0.67	0.08	0.14	2.33	74.73	8.94	0.48
	5	R	8.28	0.37	0.07	0.11	2.72	78.99	8.97	0.49
		D	12.96	0.63	0.08	0.14	2.20	74.49	9.02	0.48

R: residual stream
D: distillate stream
ND: not detected

yield of that stream.

Oleic acid content and distillate yield as a function of temperature and pressure were given in Figs. 4a and 4b, respectively. Since the objective was maximizing both oleic acid content and distillate yield simultaneously, distillation conditions in red zones (darker regions) were more preferable which corresponded to higher temperatures and higher vacuums. The equations for these surface plots were:

$$f_{Yield} = -739{,}3418 + 8{,}2971 \times T - 155{,}4749 \times p - 0{,}0207 \times T^2 + 0{,}7951 \times p \times T - 4{,}0387 \times p^2 \quad (6)$$

$$f_{Oleic} = -32{,}2102 + 1{,}1333 \times T - 10{,}9165 \times p - 0{,}003 \times T^2 + 0{,}0571 \times p \times T + 0{,}7652 \times p^2 \quad (7)$$

where p was log [P]. These empirical quadratic equations (Eqs. 6 and 7) were identified in the multi - objective study to maximize simultaneously. In multi-objective optimization, it is possible to have multiple peak points in contrast

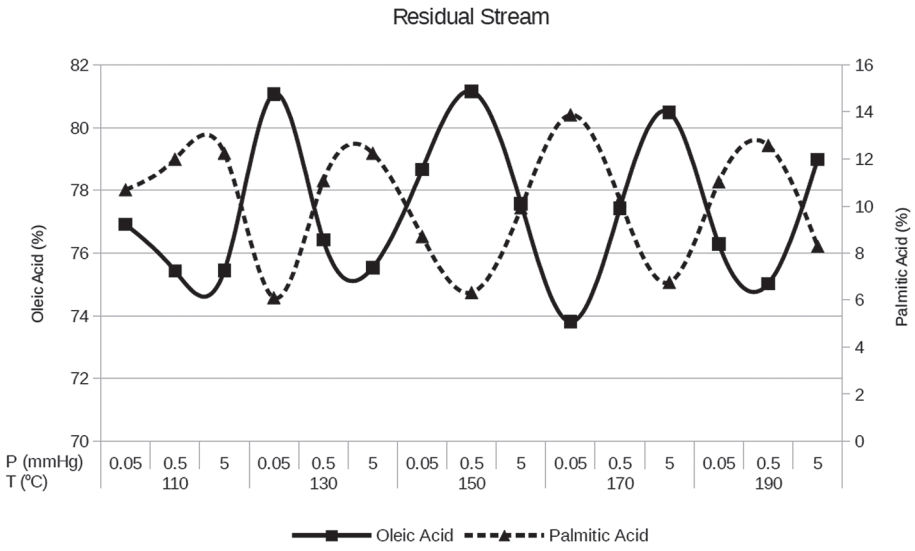


Fig. 2 Fluctuating relation between oleic acid and palmitic acid compositions of residual stream.

Table 4 Mass and oleic acid amounts of distillate and residue streams.

		Mass		Oleic Acid Concentrations		Oleic Acid Amounts		Total Oleic Acid (g)
T (°C)	P (mmHg)	Distillate (g)	Residue (g)	Distillate (%)	Residue (%)	Distillate (g)	Residue (g)	
110	0.05	3.42	62.25	63.67	76.92	2.18	47.88	50.06
	0.5	0.00	68.86	0.00	75.43	0.00	51.94	51.94
	5	0.00	68.77	0.00	75.44	0.00	51.88	51.88
130	0.05	31.95	34.77	69.66	81.07	22.25	28.19	50.44
	0.5	4.08	61.63	64.59	76.42	2.63	47.10	49.73
	5	0.00	66.29	0.00	75.54	0.00	50.08	50.08
150	0.05	57.45	7.15	74.95	78.66	43.06	5.62	48.69
	0.5	28.57	36.80	69.74	81.15	19.92	29.86	49.78
	5	12.07	53.84	69.94	77.58	8.44	41.76	50.21
170	0.05	58.81	7.51	75.82	73.80	44.59	5.54	50.13
	0.5	58.49	8.92	75.09	77.43	43.92	6.90	50.82
	5	33.56	33.37	71.72	80.48	24.07	26.86	50.93
190	0.05	60.74	6.76	75.35	76.28	45.77	5.16	50.92
	0.5	61.61	5.47	74.73	75.02	46.04	4.10	50.14
	5	59.31	7.49	74.49	78.99	44.18	5.91	50.09

to single objective optimization. According to Pareto optimality, efficacy of one function cannot be improved without renunciation from other functions[17, 18]. For this balance, weight factors are used for combining multiple functions into one single function[17]. In this study, our aim was to separate oleic acid from the mixture with the highest purity as possible. Pre-experiments showed that the most suitable weight factors would be $w_1 = 0.75$ for oleic acid and $w_2 = 0.25$ for distillate yield. Therefore, we gave priority to function of oleic acid and optimization procedure was set to focus on increasing the purity of oleic acid rather than distillate yield. Then, the best optimum condition for both individual cases was chosen among the feasible results of the Pareto front.

Verification of optimized distillation conditions

Temperature of the optimum condition was calculated as 177.36℃ and pressure was 0.051 mmHg. At this optimized

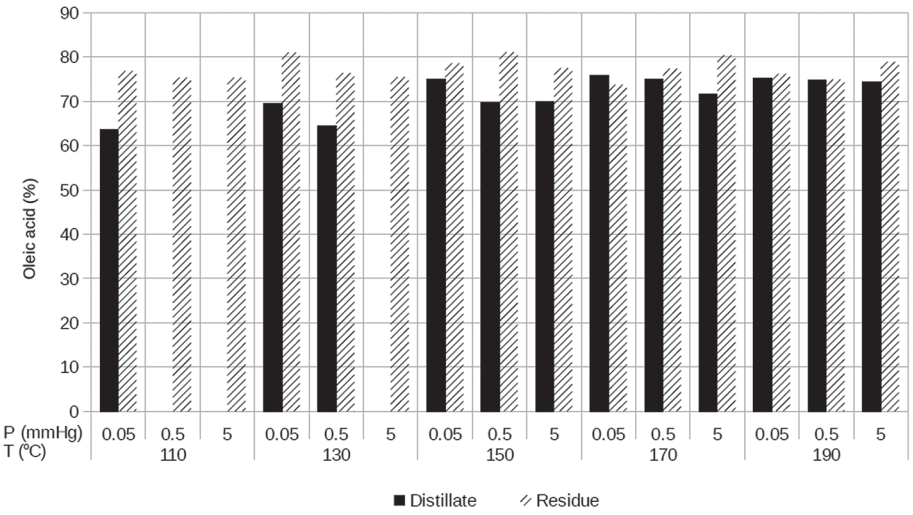


Fig. 3 Oleic acid compositions of distillate and residual streams for each distillation trial.

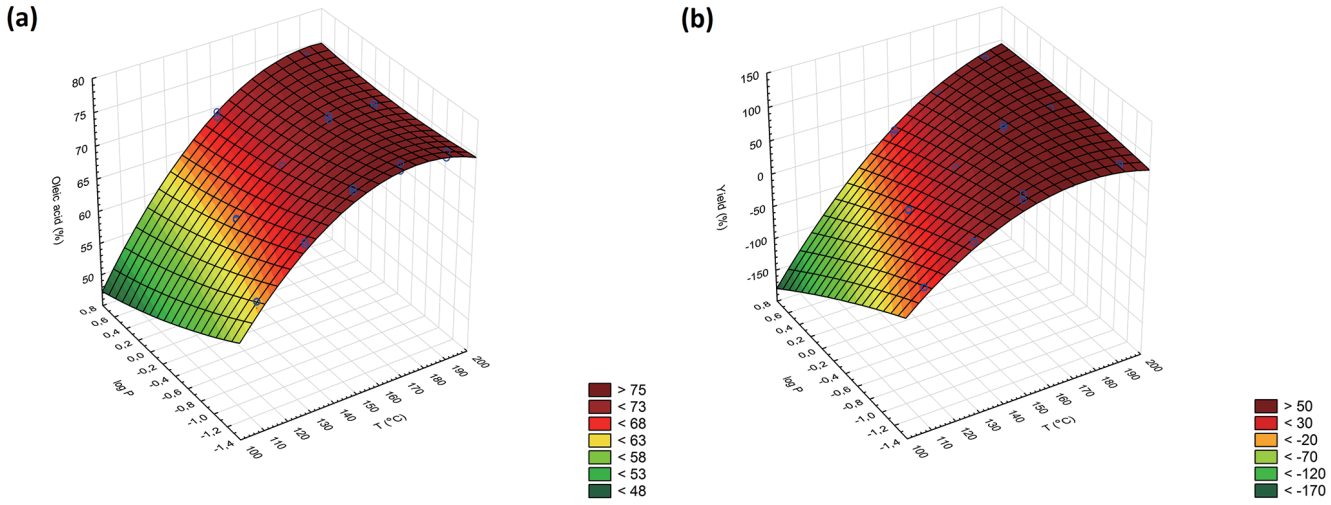


Fig. 4 (a) P-T related surface plots for oleic acid of distillate streams, (b) P-T related surface plots for yield percentages of distillate streams.

condition, 90% of data was assumed to be in the following ranges for distillate yield and oleic acid:

Range for distillate yield: 88.36% - 95.39%

Range for oleic acid amount: 75.92% - 77.19%

Additional experimental distillations were then performed to verify the optimization process at the given optimum conditions where distillate yield and oleic acid concentration was 87.66% and 75.39%, respectively. The experimental results were found very close to optimized results. Also, the resulting values from the Eqs. 6 and 7 for the given optimum conditions were 93.1% for distillate yield and 76.7% for oleic acid. The oleic acid content was in a closer range compared to the distillate yield due to choosing the weight factor aiming to increase the oleic acid. It was also important that the optimum point, to simultaneously increase the distillate yield and oleic acid content by directing the focus to the oleic acid, was lower than the high temperature range tried in the experimental design. This is also expected to enable the decrease of the risks for thermal decomposition and degradation.

Conclusion

Yields of distillate streams could be increased by temperature elevation at a constant pressure. However, this is limited by the applied vacuum. Distillate yields no longer increased when temperature raised above 150℃ under 0.05 mmHg. On the contrary, temperature increment still affected distillate yields at lower vacuums. In addition, pressure dependence of distillation yield was no longer observed at 190℃. Oleic acid could not be effectively transferred to distillate stream at low evaporation temperatures due to rapid evaporation of palmitic acid. Results revealed

that distillation of these two FAs showed a fluctuating correlation, however sum of them remained constant at 85-87% in all trials. Concentrations of all other minor FAs in the mixture did not significantly change during distillations. Higher temperatures enabled oleic acid to evaporate easily. Maximum concentration of oleic acid was experimentally found 75.82% in distillate stream at 170℃ temperature and 0.05 mmHg conditions, and minimum oleic acid concentration was obtained 63.67% at 110℃-0.05 mmHg where palmitic acid was maximum with 24.32%. In order to maximize both distillate yield and oleic acid concentration in distillate stream, a multi-objective optimization was performed. The estimated optimum value where these two functions go maximum was 177.36℃ and 0.051 mmHg. In the next step, the optimized conditions were verified as 87.66% of distillate yield and 75.39% of oleic acid. Since there are limited data sets for evaporation line of oleic acid in literature, this study could be a pioneer for further research and reveal P-T relation of oleic acid for obtaining higher purities.

Acknowledgements

This research was supported by the Scientific and Technical Research Council of Turkey, project no: 114O166 (TOVAG-Agriculture, Forestry and Veterinary Research Grant Committee).

Conflict of Interest

Authors have declared no conflict of interest.

References

1) Oleic acid[MAK Value Documentation]. *The MAK Collection for Occupational Health and Safety*. doi: 10.1002/3527600418.mb11280kske0017(2002).
2) Kamogawa, K.; Akatsuka, H.; Matsumoto, M.; Yokoyama, S.; Sakai, T.; Sakai, H.; Abe, M. Surfactant-free O/W emulsion formation of oleic acid and its esters with ultrasonic dispersion. *Colloids Surf., A* **180**, 41-53 (2001).
3) O'Brien, R.D. *Fats and oils: Formulating and processing for applications*. 2nd ed. CRC Press, LLC, 680 p(2004).
4) Gunstone, F.D. *Oils and fats in the food industry. Food industry briefing series*. Wiley-Blackwell Publishing, 160 p(2008).
5) Lopez-Huertas, E. Health effects of oleic acid and long chain omega-3 fatty acids(EPA and DHA)enriched milks. A review of intervention studies. *Pharmacol. Res.* **61**, 200-207(2010).
6) Terés, S.; Barceló-Coblijn, G.; Benet, M.; Álvarez, R.; Bressani, R.; Halver, J.E.; Escribá, P.V. Oleic acid content is responsible for the reduction in blood pressure induced by olive oil. *Proc. Natl. Acad. Sci. USA* **105**, 13811-13816(2008).
7) Carrillo, C.; Cavia Mdel, M.; Alonso-Torre, S. Role of oleic acid in immune system; mechanism of action; a review. *Nutr. Hosp.* **27**, 978-990(2012).
8) Bes-Rastrollo, M.; Sánchez-Villegas, A.; de la Fuente, C.; de Irala, J.; Martínez, J.A.; Martínez-González, M.A. Olive Oil Consumption and Weight Change: The SUN Prospective Cohort Study. *Lipids* **41**, 249-256(2006).
9) Yuan, W.; Hansen, A.C.; Zhang, Q. Vapor pressure and normal boiling point predictions for pure methyl esters and biodiesel fuels. *Fuel* **84**, 943-950(2005).
10) Ceriani, R.; Meirelles, A.J.A. Predicting vapor–liquid equilibria of fatty systems. *Fluid Phase Equilib.* **215**, 227-236(2004).
11) AOCS. *Official Method and Recommended Practices of the AOCS. Method No: Ca 5a–40*. 5th ed. Champaign, IL(2003).
12) Hammond, E.G.; Wang, T. Method of converting free fatty acids to fatty acid methyl esters with small excess of methanol. *US Patents*, US6965044 B1(2005).
13) Rajković, R.Z.; Zrnić, N.Đ.; Kirin, S.D.; Dragović, B.M. A review of multi-objective optimization of container flow using sea and land legs together. *FME Trans.* **44**, 204-211(2016).
14) Bandyopadhyay, S.; Saha, S. Some single-and multiobjective optimization techniques. in *Unsupervised Classification*, Springer Berlin Heidelberg, pp. 17-58 (2013).
15) NCBI. Oleic acid[Internet]. National Center for Biotechnology Information. PubChem Compound Database; CID=445639, https://pubchem.ncbi.nlm.nih.gov/compound/445639 Accessed 15 February 2016.
16) NCBI. Palmitic acid [Internet]. National Center for Biotechnology Information. PubChem Compound Database; CID=985, https://pubchem.ncbi.nlm.nih.gov/compound/985 Accessed15 February 2016.
17) Nguyen, H.A.; van Iperen, Z.; Raghunath, S.; Abramson, D.; Kipouros, T.; Somasekharan, S. Multiobjective optimisation in scientific workflow. *Procedia Comput. Sci.* **108**, 1443-1452(2017).
18) Caramia, M.; Dell'Olmo, P. Multi-objective Optimization. in *Multi-objective management in freight logistics: Increasing capacity, service level and safety with optimization algorithms*, Springer Science & Business Media, pp. 11-36(2008).