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Soap Production from Waste Cooking Oil: A Review

Bijak Riyandi Ahadito[1*] and Siti Rakhmi Afriani[2]

[1] Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya, Indralaya 30662, South Sumatera, Indonesia.
[2] Division of Plantation Production Technology, Department of Civil Engineering, Politeknik Negeri Sriwijaya, Palembang 30128, South Sumatera, Indonesia.

*Corresponding Author: bijak@mipa.unsri.ac.id

Abstract

In the process of cooking, chemical reactions that happen to the vegetable oil render it unfit for consumption after multiple reusage, thus turning the oil into waste. Due to the abundance of such waste, it is important to have an easy way to turn waste cooking oil into another useful commodity. Production of soap is one of such method that could be widely applied by the public due to the easiness of its procedures and no involvement of hazardous chemical, in contrast to the production of biodiesel or biofuel which sometimes demands the use of unsafe materials or conditions. The objective of this publication is to provide information about the differences between unused and used cooking oil, to lay out the methods of soapmaking, to review the academic reports of soapmaking from waste cooking oil, and to summarize the challenges that are still unsolved in this topic.

Keywords: Used Cooking Oil, Cold Process, Saponification, Soapmaking

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Ketika memasak menggunakan minyak goreng, terjadi reaksi-reaksi kimia yang menyebabkan minyak tersebut menjadi tidak layak konsumsi setelah beberapa kali penggunaan ulang. Proses tersebut membuat minyak goreng bekas atau minyak jelantah dikategorikan sebagai limbah. Dikarenakan potensi jumlah limbah yang sangat besar, diperlukan sebuah strategi yang mudah diaplikasikan untuk mengubah minyak jelantah menjadi barang lain yang lebih bermanfaat. Pembuatan sabun adalah salah satu cara yang bisa ditempuh karena kemudahan prosesnya dan tidak terlibatnya zat-zat berbahaya di dalam proses tersebut. Hal ini bertolak belakang dengan produksi biodiesel atau bahan bakar berbasis biomassa lain yang terkadang mengharuskan penggunaan zat kimia atau kondisi reaksi yang berbahaya. Publikasi ini bertujuan untuk memberikan informasi mengenai perbedaan antara minyak goreng baru dan bekas, untuk menjelaskan metode pembuatan sabun, dan untuk meninjau laporan-laporan akademis terkait pembuatan sabun dari minyak jelantah, serta untuk menyimpulkan tantangan-tantangan yang masih belum terpecahkan pada topik ini.

Kata Kunci: Minyak Jelantah, Proses Dingin, Saponifikasi, Pembuatan Sabun

INTRODUCTION

Waste cooking oil (WCO; also known as ‘used cooking oil’, UCO, among other names) is a byproduct of cooking with methods that use a notable amount of cooking oil or frying oil, i.e. frying and deep frying. It is one of the most common waste produced by Indonesian households and culinary industries. In the process of heating, the composition of cooking oil changes due to hydrolysis, thermal degradation, oxidation, and polymerization reaction that happened between the oil, water, and/or air at high temperature [1]. These reactions produce volatile and non-volatile harmful oxidation products, such as peroxides, hydroperoxides, aldehydes, ketones, carbonyl, thiobarbiturates, and also oligomeric, polimeric, and cyclic fatty acids [2, 3]. While the volatile compounds could be released to the atmosphere, non-volatile compounds would be deposited in the remaining oil and in the food that were cooked in the oil. Consumption of such foods have been found to be dangerous for human health by increasing risks of cardiovascular diseases, cancers, and many other [4–6]. If cooking oil is reused, the amount of noxious compounds also increased [4]. Therefore, after being used for a couple of times, cooking oil is no longer suitable for human consumption and thus becomes waste.

According to The International Council on Clean Transportation, the amount of WCO produced in Indonesia potentially reaches 715 million kilograms per year, with only around 25% of those processed [7]. Considering the sheer amount of waste resulted and the lack of regulation [8], untreated waste cooking oil poses a danger to terrestrial and aquatic environment [9]. Hence, the importance of having a strategy for managing WCO by recycling cannot be downplayed.

A common pathway to utilize WCO is to use it as a starting material in the production of biodiesel by converting triglycerides and free fatty acids contained within it into fatty acid methyl ester (FAME) through transesterification reaction. However, this process involves delicate reaction conditions and/or deleterious chemicals, thus are not easy to be applied by the general public [10–12]. Another way to make use of WCO as an energy source is by turning it into hydrocarbons through pyrolysis, but this process requires an even harsher reaction conditions than the aforementioned synthesis [1, 13–14].

In addition to its use as energy source, WCO could also be used as material for value-added products, such as animal feed [1]. However, using WCO as animal feed could reintroduce noxious chemicals into the food chain through the consumption of livestock meat, and as such the practice has been banned in the European Union since 2002 [15]. Another product that could be made from WCO is soap [1]. Compared to transesterification or pyrolysis, the conversion of WCO into soap is an uncomplicated process and only uses mildly dangerous substances, which makes it suitable for widespread application and home industry to support circular economy programs. The following sections review the properties of used cooking oil in comparison to unused cooking oil, the synthesis of soap from vegetable oils, and previous reports on the production of solid soap from waste cooking oil.

PROPERTIES OF USED COOKING OIL COMPARED TO UNUSED OIL

There are several kinds of vegetable oil that are commonly used as cooking oil. For frying specifically, oils with high smoke point is preferable. Globally, the most common vegetable oil consumed is palm oil (36.2%), followed by soybean oil (28.0%), canola/rapeseed oil (14.4%), sunflower oil (9.4%), palm kernel oil (4.0%), peanut oil (2.9%), cottonseed oil (2.3%), coconut oil (1.7%), and olive oil (1.1%) [16]. Usually, cooking oil in one region contains different kind of vegetable oil compared to the other region. For example, canola/rapeseed oil is the most common vegetable oil used in the European Union [17] and Japan [18], while soybean oil is the most common in the United States of America [19]. In Indonesia, the most common oil used for frying is palm oil (57.7%), followed by soybean oil (13.8%), palm kernel oil (13.6%), copra oil (6.8%), peanut oil (6.2%), and coconut oil (1.9%) [20]. **Table** 1 compares the fatty acid composition of palm oil [21], canola oil [22], and soybean oil [23] as published by The United States Department of Agriculture.

Table 1. Composition of palm, canola, and soybean oil

Parameter	Palm oil	Canola oil	Soybean oil
Saturated fatty acid (total, %)	**49.30**	**7.37**	**15.70**
Lauric acid (C12:0)	0.10	–	–
Myristic acid (C14:0)	1.00	–	–
Palmitic acid (C16:0)	43.50	4.30	10.50
Margaric acid (C17:0)	–	–	0.03
Stearic acid (C18:0)	4.30	2.09	4.44
Arachidic acid (C20:0)	–	0.65	0.36
Behenic acid (C22:0)	–	0.33	0.37
Monounsaturated F.A. (total, %)	**37.00**	**63.23**	**22.83**
Palmitoleic acid (C16:1)	0.30	0.21	–
Oleic acid (C18:1)	36.60	61.70	22.60
Eicosenoic acid (C20:1)	0.10	1.32	0.23
Polyunsaturated F.A. (total, %)	**9.30**	**28.14**	**57.79**
cis-Linoleic acid (C18:2 n-6 c,c)	9.10	19.00	51.00
α-Linolenic acid (C18:3 n-3 c,c,c)	0.20	9.14	6.79
Trans F.A. (total, %)	**–**	**0.40**	**0.53**

Knothe and Steidly collected 22 cooking oil samples from 16 collection points in Illinois, USA and analyzed their properties before and after usage [24]. The difference in the composition between used and unused oil can be seen on **Table** 2. Cooking using vegetable oil increases the oil's acid value, which represents the amount of free fatty acid (FFA) in an oil sample, due to hydrolysis reaction. This is in contrast to unused oil, in which fatty acids exist mostly, if not completely, in their triglyceride form. Thermal degradation could introduce saturation which can be seen on the increase of saturated fatty acids (SFAs) C16:0 and C18:0, and also in the decrease of polyunsaturated fatty acids (PUFAs) C18:2 and C18:3. Meanwhile, oxidation could add more unsaturated bonds in the fatty acid, which is represented by the increase of monounsaturated fatty acid (MUFA) C18:1 [1]. Similar results could be seen from the report by Abidin, et al., in which SFAs were increased by 2.82%, MUFA were increased by 11.15%, and PUFAs were decreased by 9.29% after usage compared to unused soybean oil [25]. The observed increase in viscosity could be attributed to the increase of FFA, as the viscosity of FFA are noticeably higher than triglyceride [26]. Reuse of cooking oil also darkened the oil's color, possibly caused by other thermal degradation, oxidation, and/or polymerization products.

Table 2. Difference in properties between used and unused vegetable oils [24]

Oil Sample	Properties difference after usage						
	Acid value	Viscosity (mPa·s)	C16:0 (%)	C18:0 (%)	C18:1 (%)	C18:2 (%)	C18:3 (%)
A–1	0.77	4.90	2.11	0.97	3.22	–5.11	–0.77
A–2	5.38	8.18	1.34	0.88	6.56	–7.78	–2.74
A–3	9.85	7.85	2.61	0.77	8.90	–11.34	–2.63
B–1*	0.55	–5.78	0.15	–0.56	0.75	–0.78	0.07
B–2*	0.67	–6.21	1.32	–2.28	1.79	–2.57	–0.25
B–3	0.22	12.10	9.98	–0.54	3.77	–15.80	–1.03
C–4*	6.16	5.66	4.26	–0.30	9.44	–13.57	–2.48
D–1	6.27	8.28	–1.11	–0.12	1.36	–1.37	0.43
D–2	6.35	11.12	–0.68	0.17	1.37	–0.82	–1.03
D–3	6.48	11.88	0.15	0.31	1.51	–2.02	–0.70
E*	0.69	–4.90	1.20	0.99	6.70	–3.89	–1.30
F	0.33	9.05	1.39	1.02	6.16	–6.57	–2.24
G	0.56	11.66	1.57	1.03	2.38	–3.37	–2.41
H	8.12	12.75	1.85	2.63	15.34	–15.14	–4.57
I*	3.87	6.98	2.68	0.16	4.81	–8.78	–2.39
J*	1.50	2.18	2.85	–0.18	4.51	–5.34	1.05
K*	0.39	1.63	1.25	3.10	5.26	–7.47	–2.18
L	2.58	10.25	1.43	1.36	5.48	–7.29	–2.46
M	8.91	8.07	2.77	0.79	6.19	–3.40	–0.84
N*	8.81	4.47	4.02	2.43	12.43	–15.56	–2.84
O	0.44	3.82	1.67	1.48	3.03	–3.40	–2.38
P	9.70	6.32	3.47	3.78	–8.41	–2.73	–4.08
Average	+4.03	+5.92	+2.10	+0.81	+4.66	–6.55	–1.72

Samples indexed with different alphabet indicates that the sample was taken at different places. Multiple samples taken from one place is indicated further with number, i.e. A–1 means "the first sample taken at place A". Dynamic viscosity was determined at 39.6 °C, except for samples marked with asterisk (*), which were determined at 39.2 °C.

In another publication, Awogbemi, et al. [27] also noted that different kind of food cooked in the vegetable oil could also alter the fatty acid composition of WCO. For example, palm oil used to cook fish will have more SFA compared to the same oil used to cook sausage due to leaching of SFAs from the fish into the oil. In general, we should expect waste cooking oil taken from different sources to widely vary in their physicochemical properties and fatty acid compositions between each other.

PRODUCTION OF SOAP FROM VEGETABLE OILS

The conversion of vegetable oils into soap was done mainly by direct saponification reaction, in which triglycerides and free fatty acids are hydrolyzed under alkaline condition using either sodium or potassium hydroxide. This reaction produces alkali salt of fatty acid and glycerol [28, 29]. The state of the salt, which is the main ingredient of the soap, depends on the alkali used for the reaction. If the hydrolysis were carried out using NaOH, the soap would be solid. On the other hand, using KOH would yield a thick paste that could be turned into liquid or soft soap [30]. In Indonesia, commercially available soap must adhere to the standards outlined in the Indonesian National Standard (SNI), namely SNI 3532:2021 for solid bath soap [31], SNI 2878:2021 for solid antiseptic bath soap [32], SNI 4768:2018 for solid baby bath soap [33], SNI 4085:2017 for liquid bath soap [34], SNI 2048:2020 for solid dish soap [35], and SNI 2588:2017 for liquid hand soap [36]. From here onwards, we will focus on the production of solid soap.

There are two saponification processes that could be used to produce solid soap from vegetable oils: hot and cold saponification. In the hot process, the oil is heated up to 70 °C and subsequently reacted with NaOH solution, and then the glycerol was separated from the mixture by using brine. Finally, the produced soap could then be pressed into a mold to give its shape. For the cold saponification, both the oil and NaOH solution is reacted at room temperature without removing glycerol from the reaction mixture. The produced soap could then be poured into a mold before it solidifies, eliminating the need of a pressing machine [37].

Two important parameters that must be taken into account when making soap from oils are the oil's iodine value (IV) and saponification value (SV or SAP value; also known as "saponification number", SN). Iodine value represents the degree of unsaturation in the oil [28], which can be determined by iodometric titration [38]. Saponification value shows how much base is needed to saponify the oil [28], which can also be determined by titration using KOH [39]. An equivalent SV when using NaOH as saponifying base could then be calculated using Equation 1. For fatty acids with the same chain length, higher IV means that its molecular weight would be lower, which means that it has more moles per gram, and consequently would require more base to neutralize, thus higher SV. There are different ways to express the unit for IV and SV, with ISO standard using gram of iodine per 100 grams of oil for IV [38] and milligram of base per gram of oil for SV [39]. For this publication, we will use gram of iodine/base per gram of oil as the preferred unit to preserve consistency between the two quantities and, specifically in the case of SV, to properly show the ratio between base and oil in soap production.

$$SV_{NaOH} = SV_{KOH} \times \frac{M_r\ NaOH}{M_r\ KOH} = SV_{KOH} \times \frac{40.00}{56.11} \quad (1)$$

Creation of soap from natural oils and fats have been known since ancient times [40], and it has been studied to the point that the properties of the produced soap could be consistently predicted from its starting materials and could even be fine-tuned by modifying the composition of its constituent oils and/or fats. Phanstiel, et al. provided details of the color, texture, and odor of soaps made from 15 saponifiable oils and fats in their publication [41]. An even bigger compendium could be seen from Hornsey's book titled "How to Make Your Own Soap in Bars, Liquid and Cream" in which she detailed the properties of the soap down to the fatty acid contained in the mixture of oils and fats used in soapmaking, and also the effects of additional ingredients, i.e. perfume and coloring agent, to the soap [42]. **Table** 3 below shows the IV, SV, and known properties of soap made from vegetable oils.

Table 3. Properties of some vegetable oils and soap made from them

Vegetable Oil	IV	SV_{NaOH}	Soap Properties	Ref
Castor oil	0.87	0.127	Forms a lot of foams quickly.	[42]
Coconut oil	0.08	0.180	Hard texture, rich lather, moisturizing.	[42]
Olive oil	0.86	0.134	Ivory- or white-colored, mild and flaky texture, good for skin conditioning.	[41], [42]
Palm oil	0.50	0.141	Hard and waxy texture.	[42]
Palm kernel oil	0.17	0.155	Very hard texture, fluffy lather, moisturizing.	[42]
Rice bran oil	1.12	0.129	Slow to create lather, soft and moisturizing.	[42]
Sunflower oil	1.27	0.134	White-colored, smooth and creamy texture, deteriorates easily in the soap.	[41], [42]

PRODUCTION OF SOLID SOAP FROM WASTE COOKING OIL

Compared to the knowledge of soapmaking, academic reports of soap production from WCO are surprisingly recent. The earliest publication on this topic was the 2017 report by Félix et al. [43] which described the synthesis of soap from WCO and its mixture with other oils and fats using NaOH:oil ratio in the range between 0.119 and 0.147 – a base-oil ratio that resemble the SV_{NaOH} values of some common oils. In their report, it was found that soap made only from WCO exuded during maturation which reduced its visual appeal. This could be mitigated by mixing WCO with olive, palm, and coconut oil with the ratio of 10:4:3:3 using base ratio of 0.143, which produced soap with good sturdiness, texture, and odor [43]. In 2018, Sanagueno-Salguero et al. reported that the method which produced the best-performing soap exclusively from WCO is using hot saponification with NaOH:oil ratio of 0.150 and 12 hours of maturation in the mold [44].

As WCO will have varied composition between samples due to the variety of vegetable oils available and the difference in reusage of the oil, the biggest problem with making soap from WCO would be consistency. 2018 publication by Adane [45] demonstrates this problem well, in which the author reported the variance in IV and SV between three samples of WCO taken from hotels, restaurants, and street food vendors in Ethiopia, which can be seen on **Table** 4. Assuming that the oil used by the hotel, restaurant, and street vendor are of the same type and the darkness of its color correlates with the amount of reusage the oil has been through, the report indicates that more reusage increases the SV of the oil and reduces the ability of the soap produced from it to cleanse compared to commercial soaps.

Table 4. Properties of soap made from differently-sourced WCO

Properties	Street Vendor WCO	Restaurant WCO	Hotel WCO
Oil color	Orange	Brown	Dark brown
IV	0.320	0.300	0.310
SV_{KOH}	0.197	0.205	0.201
Soap color	Light yellow	Orange	Brown
Cleansing power	High	Good	Medium

An important step that could be done to enhance the quality of WCO used to make soap is pretreatment. By removing unwanted byproducts of oil reusage, the soap made from WCO would hopefully be better in quality. A simple filtration to remove solids could be a good enough pretreatment process for lightly-reused WCO, but would not be sufficient for highly-reused WCO which contains more byproducts. Arlofa et al. [46] reported that WCO which have undergone a pretreatment series of filtration, neutralization with NaOH, and bleaching using activated carbon could be used to produce soap that adheres to Indonesian National Standard for solid bath soap. An interesting utilization of WCO pretreatment could be found in the 2023 publication by Tukan et al. [47], in which the authors reported the usage of coffee waste as adsorbent in WCO pretreatment. It was found that the soap made from it were slightly transparent in contrast to fully opaque soap bars that were reported in previously mentioned reports.

Production of soap from WCO is inherently a circular economy process. Therefore, it is also important to see this process through an economic perspective. In their 2020 report, Mustakim et al. [48] analyzed the economic viability of soap production. They concluded that with the production cost of IDR 578 per bar, breakeven point could be reached after selling 200 bars of soap per year at the price of IDR 1000, with a payback period of 11 months. An important point to note in that publication is that the authors set the cost of WCO as a production material at zero. This implies that the aforementioned analysis would be valid only if you have your own steady supply of self-made WCO that is plenty enough for routine production, e.g. restaurant owners.

CONCLUSION

Production of soap is a viable way to utilize waste cooking oil. The changes that happen to vegetable oil in the process of cooking render the oil to be inconsumable after a few reusage, thus making it a dangerous household waste. While production of soap from fresh vegetable oil has been extensively studied, the same could not be said about soapmaking from WCO. Production of soap from WCO in a consistent manner would be difficult due to variance in composition between WCO samples. However, pretreatment of WCO by filtration, neutralization, and/or adsorption could help to enhance the quality of the oil used and also soap produced from it. Soapmaking from WCO could also be an applicable way to generate income with relatively low breakeven point and short payback period. Further research is needed in order to tackle the challenge of production consistency, and also to give a better economic analysis that is more generally applicable.

DECLARATION OF COMPETING INTEREST

The authors are co-owners of “Nirsampah”, a small-scale private enterprise (UMKM) in Palembang, Indonesia which specializes in production of goods from recycled materials including soap from waste cooking oil.

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