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Converting Used Cooking Oil into Household Soap by Optimized Cold-Process Saponification

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إنتاج الصابون المنزلي من زيوت الطهي المستعملة باستخدام تقنية التصبن البارد المحسنة

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Abstract:
Discharge of used cooking oil (UCO) into drains and soil is a persistent problem wherever organized waste collection is weak. This study converted pre-treated UCO into household soap by the cold process and compared eight formulations. Oil gathered after three to five frying cycles was settled, filtered, washed with brine and bleached with hydrogen peroxide under sunlight. The formulations differed in sodium hydroxide concentration and alkali-to-water ratio, and each was assessed for pH, iodine decolorization time, foam height and stability, moisture, hardness, stain removal and appearance. Formulation F2 (10% NaOH, 75:25 ratio) gave the best overall profile: a pH of 9.1, the fastest iodine decolorization (28 s), the tallest and most stable foam (132 mm; 88%) and a grease-removal score of 4.8 out of 5. Formulations made with 25% NaOH (F5–F8) had pH values of 10.6–11.2 and weaker cleaning and foaming. Low-cost conversion of UCO into soap is therefore a workable small-scale route for resource recovery, provided that alkali is carefully controlled. These findings highlight the importance of optimizing alkali concentration to achieve a balance between soap quality, cleaning efficiency, and product safety. Furthermore, the utilization of UCO offers an environmentally beneficial approach to reducing waste disposal while promoting the recovery of valuable resources through sustainable soap production.

Keywords: Used Cooking Oil; Saponification; Waste Valorization; Formulation Optimization.

الملخص
يتم التخلص من زيوت الطهي المستعملة في شبكات الصرف الصحي أو التربة مشكلة بيئية، خاصة في المناطق التي تفتقر إلى أنظمة فعالة لجمع النفايات. هدفت هذه الدراسة إلى إعادة تدوير زيت الطهي المستعمل وتحويله إلى صابون منزلي باستخدام الطريقة الباردة، من خلال تحضير ومقارنة ثماني تركيبات مختلفة.
تم جمع الزيت بعد استخدامه في ثلاث إلى خمس عمليات قلي، ثم ترسيبه وترشيحه وغسله بالمحلول الملحي وتبييضه باستخدام فوق أكسيد الهيدروجين تحت أشعة الشمس. واختلفت التركيبات في تركيز هيدروكسيد الصوديوم ونسبة القلوي إلى الماء، وتم تقييمها من حيث الرقم الهيدروجيني والرغوة وثباتها والرطوبة والصلابة وكفاءة إزالة البقع والمظهر العام.
أظهرت النتائج تفوق التركيبةF2 ، التي تحتوي على 10% من هيدروكسيد الصوديوم وبنسبة 75:25، حيث سجلت أفضل أداء من حيث الرقم الهيدروجيني (9.1) وثبات الرغوة (88%) وكفاءة إزالة الدهون (4.8 من 5)، كما حققت أعلى ارتفاع للرغوة بلغ 132 مم. في المقابل، أظهرت التركيبات التي تحتوي على 25% من هيدروكسيد الصوديوم ارتفاعا في الرقم الهيدروجيني وانخفاضا في كفاءة التنظيف وتكوين الرغوة.

وخلصت الدراسة إلى أن تحويل زيوت الطهي المستعملة إلى صابون يعد وسيلة عملية ومنخفضة التكلفة للحد من النفايات والاستفادة منها، مع التأكيد على أهمية ضبط تركيز هيدروكسيد الصوديوم لضمان جودة المنتج وكفاءة التنظيف وسلامته، بما يدعم مبادئ الاستدامة والاقتصاد الدائري.

الكلمات المفتاحية: زيت الطهي المستعمل؛ التصبن ؛ تثمين النفايات؛ تحسين تركيبة المنتج.

Introduction

Frying generates large quantities of waste oil. Reviews put the global output of used cooking oil at 41 to 67 million tonnes a year [1]. Where there is no organized collection, much of it is poured into sinks or onto the ground. In sewers it contributes to fats, oils and grease deposits that block pipes and raise the cost of wastewater treatment [2,3], and its disposal to landfill or sewer can cause serious environmental harm [4,5].

Frying changes the oil chemically. Hydrolysis releases free fatty acids, oxidation yields peroxides, aldehydes and ketones, and thermal polymerization thickens and darkens the oil [6]. Even so, the bulk of UCO is still triglyceride and fatty acid, similar to the fresh oil apart from its breakdown products [1], so it remains a usable chemical feedstock.

Biodiesel is the best-known outlet for waste frying oil [7,8]. It requires catalysts, controlled conditions and product purification, and free fatty acids in the oil interfere with alkaline transesterification [1,9]. Pre-treatment of the oil adds further steps and cost [10]. Alkaline saponification is far less demanding. Hydroxide cleaves the ester bonds of triglycerides, giving glycerol and the sodium salts of fatty acids, which are soap, and free fatty acids simply neutralize to soap as well. Little equipment is needed, so the method suits households and small community groups. Several studies have shown that acceptable soap can be made from UCO [11–13], and a recent study of oil taken after different numbers of frying cycles reported soaps that met East African standards for laundry soap [14]. The behaviour of the bar, including its hardness, lather and cleaning power, depends on the fatty acid composition of the oil, the amounts of alkali and water, and the curing conditions [15]. Changing the water ratio alone has been reported to alter foam stability and cleaning power [16]. Too much alkali leaves free caustic in the bar and makes it harsh on skin, whereas too little leaves unreacted oil and a soft, greasy product.

Pre-treatment is also needed because spent oil is dark and strongly scented. Settling and filtration remove food debris, a salt wash removes polar impurities, and peroxide bleaching reduces colour and odour; this sequence of brine refining followed by hydrogen peroxide bleaching has been applied to waste cooking oil before soap making [17]. A bar that looks and smells acceptable is more likely to be used.

The literature reports many single formulations, but fewer studies compare, within one design, how alkali concentration and alkali-to-water ratio together affect pH, surfactant activity, foam, hardness and stain removal for soap made from pre-treated UCO. The present work therefore (i) prepared eight cold-process soaps from pre-treated UCO, and (ii) compared them on physicochemical, functional and sensory characteristics to identify the most balanced formulation.

2. Materials and Methods

2.1 Materials

Used cooking oil, mainly vegetable frying oil that had been used three to five times, was obtained from the kitchen of the Kanzus Sholawat Foundation in Surakarta. Sodium hydroxide pellets (≥98%, analytical grade) came from Merck (Germany); hydrogen peroxide (30% w/w) and sodium chloride (analytical grade) from Sigma-Aldrich. Distilled water was used throughout. Stain tests used 100% cotton swatches soiled with used motor oil (grease), soy sauce (protein and tannin) or commercial red lipstick (wax, oil and pigment). All glassware was rinsed with distilled water before use.

2.2 Pre-treatment of the oil

The oil was left to settle for 48 h at 25–28 °C and the clear upper layer was passed through two layers of muslin. For the brine wash, 500 mL of filtered oil and 100 mL of warm 10% (w/v) NaCl solution were shaken together in a separatory funnel for 2 min and left for 1 h. The lower aqueous layer was discarded. For bleaching, 200 mL of washed oil was stirred with 5 mL of 30% hydrogen peroxide and kept in sunlight for 24 h. The treated oil was stored in airtight glass bottles.

2.3 Soap preparation

For each batch, 500 g of pre-treated oil was warmed to 40 ± 2 °C in a thermostatic water bath. Sodium hydroxide was dissolved slowly in distilled water under constant stirring in a well-ventilated area, because the dissolution is

strongly exothermic, and the lye was cooled to about 40 °C. Eight formulations (F1–F8) were produced by varying the NaOH concentration (10% for F1–F4 and 25% for F5–F8) and the NaOH-to-water mass ratio, which was 70:30, 75:25, 80:20 or 85:15 within each concentration group (Table 1). The lye was added gradually to the oil under mechanical stirring at about 300 rpm, and stirring continued for 45–60 min until "trace" was reached, meaning that the mixture was thick enough to leave a visible trail on its surface. No further heat was applied. The mixture was poured into cylindrical PVC moulds, wrapped in towels to retain heat during gel phase and left for 48 h. The logs were then demoulded, cut into bars and cured for six weeks at 25–28 °C in a ventilated room, which allows saponification to finish and excess water to evaporate.

Table 1. Experimental design of the soap formulations.

Formulation	NaOH concentration (% w/v)	NaOH : H_2O mass ratio
F1	10	70 : 30
F2	10	75 : 25
F3	10	80 : 20
F4	10	85 : 15
F5	25	70 : 30
F6	25	75 : 25
F7	25	80 : 20
F8	25	85 : 15

2.4 pH

One gram of grated cured soap was dissolved in 20 mL of distilled water, left for 5 min, and measured with a Hanna HI98107 pH meter. Each sample was measured in triplicate.

2.5 Iodine decolorization test

The test was used as an indirect indicator of surfactant activity. One millilitre of 5% (w/v) soap solution was added quickly to 5 mL of 0.1 N iodine solution (iodine in potassium iodide), the tube was shaken for 10 s, and the time for the brown colour to disappear completely was recorded. Shorter times mean higher surfactant activity.

2.6 Stain removal

Cotton swatches were soiled with about 5 cm^2 of one stain. Each was lathered with 0.5 g of grated soap and 10 mL of tap water, scrubbed by hand for 1 min, rinsed under running water for 30 s and air-dried. Three independent observers scored removal on a five-point scale (1 = none, 2 = slight, 3 = moderate, 4 = substantial, 5 = complete) and the mean of the three scores was used.

2.7 Foam, moisture, hardness and sensory properties

Foam height and foam stability (% of initial foam retained) after 5 min, measured by shaking 1 g of soap in 100 mL of distilled water in a stoppered 250 mL graduated cylinder, moisture content by oven-drying 2 g of soap at 105 °C to constant mass, and hardness by manual indentation (relative score) were determined on cured bars. Colour, surface homogeneity, texture and odour were recorded by observation.

2.8 Data treatment

All experiments were run in triplicate and the results are reported as means. Differences between formulations are described qualitatively, and no inferential statistical tests were applied.

3. Results and Discussion

3.1 Effect of pre-treatment on the oil

Sedimentation, filtration, brine washing and bleaching visibly improved the clarity, colour and odour of the oil. The free fatty acid content was not measured in this study, but frying is known to raise it, and the extent of the change depends on how long the oil was used and what was fried in it [18]. A moderate FFA level is not a drawback for soap making, since free fatty acids neutralize directly with alkali, in contrast to alkaline biodiesel production, where they are a problem [1]. Peroxide bleaching removed much of the dark colour and sharp smell, probably by breaking down conjugated double bonds and polymerized pigments formed during heating. Bars made from bleached oil were light amber and nearly odourless, whereas bars from untreated oil were dark brown and smelled rancid, so bleaching is a simple way to make the product more acceptable to users.

3.2 pH

The properties of the eight formulations are given in Table 2. The pH rose with alkali content, from 8.8 for F1 to 11.2 for F8.

Table 2. Physicochemical and functional properties of the cured soap formulations (F1–F8).

Formulation	pH	Iodine decolorization time (s)	Foam height (mm)	Foam stability (%)	Moisture (%)	Hardness (a.u.)
F1	8.8	35	120	82	14.5	60
F2	9.1	28	132	88	12.4	68
F3	9.4	40	115	79	11.8	72
F4	9.5	46	110	75	10.5	75
F5	10.6	62	95	66	13.2	70
F6	10.8	68	90	61	12.7	73
F7	11.0	74	85	58	11.4	76
F8	11.2	80	80	52	10.2	79

Values are means of triplicate determinations. Hardness is a relative score from manual indentation (arbitrary units).

All bars made with 25% NaOH (F5–F8) had a pH of 10.6 or higher, which points to residual free alkali; at the top of the series (F8, 11.2) the value lies above the 9–11 range cited in [14] as suitable for fabric and skin. Strongly alkaline soap can strip the skin's protective acid mantle and cause irritation. The 10% NaOH bars (F1–F4) lay between 8.8 and 9.5. F2, at 9.1, was the most balanced and is slightly below the pH of about 10 reported for other cold-process cooking-oil soaps [16]. Because pH is only an indirect indicator, titration of free alkali would be a useful complement in future work.

3.3 Surfactant activity

F2 decolorized iodine fastest (28 ± 3 s), pointing to rapid micelle formation and strong surface activity. Oleate and linoleate soaps, which are expected to be abundant in a vegetable frying oil, dissolve readily and so disperse quickly in water. All 25% NaOH formulations needed more than 60 s. A plausible explanation is that high alkalinity favours dense, poorly soluble soap structures that release surfactant slowly, although this was not examined directly here.

3.4 Stain removal

F2 gave the best removal for all three stains and scored 4.8 out of 5 on grease. Good grease removal requires a soap that emulsifies non-polar material into stable oil-in-water droplets, which a balanced fatty acid salt mixture does well. Soy sauce was removed to a moderate degree, and the high-alkali bars (F5–F8) performed worse. A possible reason is that strongly alkaline conditions can set protein stains in the fibre, but the study did not test this. Lipstick was removed effectively by the 10% NaOH group. Because the scores come from visual rating, an instrumental colour measurement would strengthen these results.

3.5 Foam

F2 had the highest foam (132 mm) and the greatest stability (88%). Soaps rich in unsaturated fatty acid salts form flexible films that trap air, while the poorly soluble matrix of the high-alkali bars limits lather, as reflected in the fall of foam stability from 88% to 52% across the series. The sensitivity of foam to the water and alkali proportions agrees with the effect of water ratio reported in [16].

3.6 Moisture and hardness

Moisture differed with the water proportion in the batch: bars that kept more water after curing were softer and wore away faster in use. Drier bars were harder and mechanically more stable but lathered somewhat less. With 12.4% moisture and a hardness of 68, F2 combined acceptable solidity with good solubility. All moisture values (10.2–14.5%) are well below the 30% limit that [14] cites from the East African standard for laundry soap.

3.7 Environmental implications

Producing soap locally from household or kitchen oil keeps it out of drains, reduces the risk of blocked pipes and avoids transporting waste to a central facility. It also offers a possible source of small income, although this study did not assess costs or markets.

3.8 Limitations and future work

The study has several limitations. The fatty acid profile and free fatty acid content of the oil were not determined, free alkali, total fatty matter and chloride content were not measured, so the soaps cannot be compared directly with standards, and the sensory and stain evaluations were subjective. Hardness was scored on a relative scale and no inferential statistics were applied, so differences between formulations are descriptive. Storage stability, microbial safety during curing, production cost and environmental impact at larger scale remain to be assessed. FTIR, thermogravimetric analysis, SEM and a life cycle assessment would give further insight into structure and environmental performance.

4. Conclusions

Cold-process saponification of pre-treated used cooking oil gave household soaps of acceptable quality. Sedimentation, filtration, brine washing and peroxide bleaching improved the colour and odour of the oil and the appearance of the bars. Formulation F2 (10% NaOH, 75:25 alkali-to-water ratio) provided the best overall performance, with a mild pH of 9.1, rapid iodine decolorization, high and stable foam, strong grease removal and moderate hardness, whereas the 25% NaOH formulations were too alkaline and less effective. These findings show that converting used cooking oil into soap is a feasible, low-cost option where formal oil collection is lacking, provided that alkali levels are carefully controlled. Future work should add fatty acid analysis, free alkali and total fatty matter determination, and storage studies.

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