



Regeneration of Used Frying Palm Oil by Inorganic Adsorbent Combinations

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Used frying palm oil was treated with ten binary-blend adsorbents composed of silica, alumina, zeolite Na4A, magnesium silicate and activated carbon. These compounds' efficacy in regenerating the oil was evaluated in terms of their effects on peroxide value, *p*-anisidine value, free fatty acids value, total polar compounds, colour and viscosity. Of the initial binary adsorbent combinations, two were selected as providing the most significant reductions in oil parameters: activated carbon:alumina and activated carbon:silica (2:1). These two binary adsorbents were then reused over the course of 15 frying cycles to test their efficiency in removing the products of oil decomposition for all of the parameters monitored. After the used binary adsorbents were treated by calcinations at 500 °C for 3 h, we observed a decrease in the absorption capacity of the reactivated adsorbents with regard to peroxide value, *p*-anisidine value, free fatty acids value, total polar compounds, total colour difference and viscosity values.

Key Words: Regeneration, Combination adsorbents, Used frying oil, Palm oil, Reused.

INTRODUCTION

One of the many challenges that confront environmental preservation efforts is the problem of oil disposal. As a solution, some have suggested recycling, rather than disposing of, used frying oils¹. Since deep-frying is a common process for preparing food worldwide²⁻⁴ the quality and stability of frying fats are of particular concern to food technologists, nutritionists and consumers. During commercial deep-frying, changes eventually occur in the frying fat that may adversely affect the food's flavour and nutritional value⁵.

Fats and oils tend to deteriorate during deep fat frying, undergoing oxidative, hydrolytic and polymerizing changes. These changes are influenced by the frying temperature and by the presence of emulsifiers, trace metals, food scraps, free fatty acids and alkaline-reacting materials in the frying oil^{1,3}. Oxidation by aerial oxygen is the most common form of deterioration that occurs in frying oil and it is relatively rapid, especially in the case of polyunsaturated oils. Free peroxy radicals are unstable intermediates and hydroperoxides, the primary oxidation products, are rather unstable under frying conditions. The latter compound reacts with the substrate, particularly with the thiol, sulphide, disulphide and primary amine groups of proteins and remains partially attached to the protein moiety. The extent to which oil triacylglycerols are hydrolyzed during deep-frying depends on the moisture from the substrate. When food material, usually at room temperature, comes in

contact with frying oil that has been preheated to between 130 and 200 °C, the water within the substrate is almost immediately heated to the boiling point. The resulting steam partially hydrolyzes the triacylglycerols into free fatty acids (FFA) and partial glycerol esters (diacylglycerol, monoacylglycerol and glycerol) during the relatively short period, about 5-10 min, of deep-frying^{1,5}. Fatty acids are more volatile than glycerides and so the smoke, flash and fire points of the oil decrease as the free fatty acid content of oil increases⁶. During the frying process, a number of changes take place in the oil, involving a complex pattern of thermolytic and oxidative reactions that can vary based on the type of oil used and the food fried. During frying, these chemical reactions form compounds with a higher molecular weight and polarity. This phenomenon then leads to the formation of new compounds (as well as the rejection of used oil) such as diacylglycerols, monoacylglycerols, free fatty acids, monomers, polymers and so on, all of which are harmful to the human body. Additionally, a number of visible changes in fat and oil occur during frying. These changes include darkened colour, increased viscosity, decreased smoke point and increased foaming^{2,7}.

Currently, the frying industry makes use of filter aids to extend the use life of frying oils and improve various aspects of used frying oil. The materials used in filter aids, whether alone or in combination, have been found to reduce the oil's acid value, peroxide value, photometric colour and polar comp-

ounds. In this respect, several adsorbent agents are used to purify used oils. Most of these agents, such as clay, magnesium silicate, activated alumina, charcoal, *etc.*, work to remove one or more of the impurities or colour bodies^{1,7-9}. Filter aid materials or their combinations have been found to be effective for controlling free fatty acids and the colour of used frying oils. A mixture of activated carbon and silica has been shown to reduce oil's acid value by 53.9 % and photometric colour by 38.3 %. However, the use of these adsorbents should be approached with care since they can affect the fat's stability³. Mancini-Finho *et al.*¹⁰, reported that oil treated with an adsorbent mixture of 4.5 % clay, 0.5 % charcoal, 2.5 % magnesium oxide and 2.5 % celite experienced significant improvements in dielectric constant change (DCC), free fatty acids and colour by 6, 14 and 58 %, respectively.

Due to both increasing oil prices and environmental concerns about pollution resulting from the incineration of certain agricultural hull wastes, the present study was designed to improve the quality of used frying palm oil and assess the feasibility of recycling the oil using certain combinations of inorganic adsorbents as regeneration agents. In addition, these regeneration agents were compared against one another in terms of efficacy and their modes of action were examined. After that the used binary adsorbents were treated with calcinations at 500 °C for 3 h before used to improve the quality of frying palm oil again.

EXPERIMENTAL

The fresh palm oil used in this study was obtained from a local processor (Tavantita Co. Ltd., Thailand) and supplied in 18 L tin cans. It was opaque at room temperature and turned pale yellow when heated. The used frying palm oils were treated using the following process: fresh palm oil (18 L) was placed in a domestic stainless steel pan fryer (60 cm diameter × 18 cm height) and heated at 180 ± 5 °C. Then, chicken samples (10 kg) were fried in the oil for about 20 min. The entire frying process was conducted twice daily and the frying period was 40 min/day. This process was repeated for 10 consecutive days and the oil's total continuous frying period was 400 min. Once the process was complete, oil samples were left to cool down, then stored in glass-stoppered flasks after being flushed with nitrogen.

Adsorbents: The five different adsorbents used in this study included zeolite Na4A (ZE) (Grandbiz Trading Ltd., Part, Thailand), alumina (AL) (Riedel-de Haën, Europe), silica (SI) (Pharma Chemica, India), activated carbon (AC) (Vol Chem, USA) and magnesium silicate (MA) (Pacific Comma Trading Ltd., Part, Thailand). Zeolite Na4A is an alkali aluminosilicate and it has an effective pore opening of about 4 Å (0.4 nm). Furthermore, it is the sodium form of the Type A crystal structure. The next adsorbent, silica, is a chemically inert, non-toxic material composed of amorphous silicon dioxide. It has an internal network of interconnecting microscopic pores, yielding a typical surface area of 700-800 square meters per gram. The third adsorbent used in the study was alumina, which typical surface area of 200-400 square meters per gram. The fourth adsorbent was activated carbon, which is a form of carbon that has been processed to make it extremely porous,

leading to a very large surface area. Finally, magnesium silicate is inert and hydrophobic. The fresh palm oil and used frying palm oil were labelled as F1 and SP20, respectively.

Batch adsorbent treatment: The ten different adsorbent combinations used in this experiment were as follows: SI:AL; ZE:AL; MA:AL; MA:ZE; MA:SI; ZE:SI; AC:AL; AC:ZE; AC:SI; and AC:MA (in ratios of 1:1, 1:2 and 2:1). A preliminary study guided our selection of the types of adsorbents to be used and their appropriate ratios. In the adsorbent treatment of the used frying oil, each adsorbent combination was preheated 80 °C, combined with the oil (SP20) in a ratio of 10 % wt/v and then stirred for 20 min. The resulting slurry was vacuum filtered through a filter paper and stored in glass-stoppered flasks after being flushed with nitrogen.

Peroxide value (PV) determination: The oil's peroxide value was determined using the Official Methods and Recommended Practices of the American Oil Chemists' Society method¹¹. Thirty mL of a treatment mixture (chloroform:acetic acid in a 3:2 v/v ratio) were used to dissolve 5 g of the oil sample along with 0.5 mL potassium iodide. Then, after adding 30 mL of water and an indicator to the flask, the mixture was shaken. Finally, the sample was titrated with 0.1M Na₂S₂O₃ and shaken vigorously until the mixture had achieved a permanent lack of colour.

$$\text{Peroxide value} = \frac{[(S - B) \times N \times 1000]}{\text{Mass of sample, g}} \quad (1)$$

where B is the volume of the blank titrant (mL), S is the volume of the sample titrant (mL) and N is the normal value of the sodium thiosulfate solution.

p-Anisidine value (p-AV) determination: The p-AV value was determined through AOCS (1998)¹¹. The sample (0.5-4.0 g) was dissolved and diluted to volume with isooctane in a 25 mL volumetric flask. The absorbance (A_b) of the solution was measured at 350 nm. Exactly 5 mL of the fat solution were transferred to a test tube, while 5 mL of the solvent were added to another test tube. One mL of p-anisidine reagent (2.5 g/L solution in glacial acetic acid) was added to each tube and shaken. After exactly 10 min, the absorbance (A_s) of the solution in the first test tube was measured at 350 nm, using the solution in the second test as blank

$$p - AV = \left[\frac{25 \times (1.2A_s - A_b)}{m} \right] \quad (2)$$

where A_s is the fat solution's absorbance after reacting with the p-anisidine reagent, A_b is the absorbance of the fat solution and m is the mass of the test portion in g.

Free fatty acids (FFA) determination: The level of FFAs in the oil was determined using the AOCS (1998) method¹¹. Fifty mL of ethanol were used to dissolve 28.2 g of the oil sample, after which 2 mL of the phenolphthalein indicator was added into the flask. Finally, the sample was titrated with a 0.1N NaOH solution and vigorously shaken until a faint pink colour appeared and persisted for at least 1 min. The FFA content was then calculated as the percentage of oleic acid present.

$$\text{FFA (\% (as oleic acid))} = \frac{(V \times N \times 28.2)}{m} \quad (3)$$

where m is the mass of the test portion (g), V is the volume of NaOH consumed (mL) and N is the normality of NaOH.

Total polar compounds (TPC) determination: The TPC level of the oil was determined using the AOCS method¹¹. A chromatographic column was filled with 30 mL of a mixture of petroleum and diethyl ether (87:13, v/v). A wad of glass wool was introduced at the lower end of the column with the aid of a glass rod. Twenty-five grams of silica gel were mixed with 80 mL of the solvent mixture. The resulting slurry was then poured into the column. The elution solvent was drained through the column until its level was 10 cm above the silica gel level. About 4 g of sea sand were added and the supernatant was then drained to the sand layer. To test TPC, 2.5 g of the oil sample were dissolved in 20 mL of the solvent mixture containing petroleum and diethyl ether (87:13, v/v). The volume was then made to 50 mL with the solvent mixture and 20 mL of the resulting solution were introduced into the column and drained off to the level of the sand layer. The non-polar compounds were eluted with 150 mL of the solvent mixture at a flow rate of 2.5 mL/min. TPC was calculated as:

$$\text{TPC (\%)} = \left[\frac{m - m_1}{m} \right] \times 100 \quad (4)$$

where m_1 is the mass (g) of the non-polar fraction and m is the mass (g) of the sample contained in 20 mL of the solution added to the column.

Viscosity measurements: Viscosity measurements were performed using a Thermo Haake Rheostress model TYP 387-001. A cone-plate sensor was used to measure the viscosity of the oil samples at 30 °C using an LV 1 spindle at 30 rpm.

Colour measurements: The colour of the oil samples was measured using a CR-300 series chromameter. The instrument was standardized with a white ceramic plate. Samples were scanned at three different locations to determine the L , a and b values as the average of the three measurements. The colour values were expressed as L (whiteness or brightness/darkness), a (redness/greenness) and b (yellowness/blueness), respectively. The total colour difference (TCD) was calculated as

$$\text{TCD} = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \quad (5)$$

where, L_0 , a_0 and b_0 refer to colour parameters of fresh oil and L , a and b refer to the oil's colour values at various times during frying.

Performance parameters: The adsorbents' performance was expressed in terms of a percentage improvement (PI %), which is an index for comparing the quality of the processed oil with that of fresh oil. The PI % for each component and the physical properties of the oil were calculated using the following equation:

$$\text{PI (\%)} = \left[\frac{[(\text{Value of untreated oil} - \text{Value of treated oil})]}{\text{Value of untreated oil}} \right] \times 100 \quad (6)$$

Reused adsorbents for frying 15 consecutive frying cycles: This experiment was designed to test and compare the efficacy of different binary adsorbent combinations for repeatedly treating frying oil. The reused adsorbents were treated by calcination at 550 °C for 3 h in each frying cycle. Each batch of adsorbent underwent this process 15 times in order to determine frying's effect on the oil's properties.

RESULTS AND DISCUSSION

Table-1 shows the values of fresh palm oil (F1) and SP20 prior to adsorbent treatment. SP20 had higher values of PV, p -AV, FFA, TPC, TCD and viscosity compared to the fresh oil. SP20 was also significantly darker, redder and yellower than the F1. From the PV and p -AV values, it is observed that the SP20 contained the oxidative deterioration and secondary oxidation products that we would expect to see in used frying oil. High levels of FFA had formed as a result of hydrolysis, oxidation, free radical formation and the cleavage of double bonds during frying. Additionally, the SP20's TPC values indicated that it had a high level of polar substances, such as monoacylglycerols and diacylglycerols, which would have occurred as the oil sample was heated. The formation of polymers during frying was mainly responsible for the changes in viscosity of the SP20. The SP20 was subjected to each of the ten adsorbent combinations and the adsorbent's efficiency in recovering the oil was tested by comparing the treated used oil to fresh oil. Details on the calculation of the percentage improvement are given in the prior section on performance parameters.

Adsorbents' efficiency depends on their polarity, surface active sites, surface area, porosity, particle size, pH and moisture content¹². Adsorbent combinations were selected after screening each adsorbent and ranking them according to their overall percentage improvement (PI %) values across all analysis parameters. The treatment of used frying oils with binary adsorbent combinations was effective in reducing of PV, p -AV, FFA, TPC, colour and viscosity of the oils. The results are expressed in Table-2 as improvements in the quality of the SP20 sample.

The oxidative deterioration of oils and fats was analyzed by looking at their peroxide values. These values measure the amount of peroxides formed in oils through the autoxidation and oxidation processes and they provide an indirect measure of the degree of initial oxidation present in oils and fats¹. Table-2 shows that the ten binary adsorbent combinations we tested were able to significantly limit the oil oxidation process during frying relative to untreated SP20. The oils treated with binary adsorbent combinations were achieved a reduction in their PVs ranging from 11.24-34.02 %.

The p -AV test primarily measures secondary oxidation products, α - and β -unsaturated aldehydes in particular. Such

TABLE-1
EVALUATION OF THE FRESH (F1) AND USED FRYING PALM OIL SAMPLE (SP20)

Sample	PV (meq/kg)	p -AV	FFA (%)	TPC (%)	Colour				Viscosity (mPas)
					L	a	b	TCD	
F1	0.995	0.060	0.074	3.81	72.00	-5.96	35.26	0.00	47.7
SP20	9.070	10.215	0.979	9.93	56.59	10.44	61.83	34.82	56.7

TABLE-2
EFFECTS OF BINARY ADSORBENT COMBINATION TREATMENTS ON THE PROPERTIES
AND PERCENT IMPROVEMENT (PI %) OF THE TREATED OIL*

Adsorbents**	Ratio (g)	PV		<i>p</i> -AV		FFA		TPC		Colour		Viscosity	
		meq/kg	PI (%)	–	PI (%)	(%)	PI (%)	(%)	PI (%)	TCD	PI (%)	mPas	PI (%)
SI:AL	1:1	6.954	23.33	6.890	32.55	0.765	21.81	6.979	29.69	15.55	55.34	51.3	0.09
	1:2	7.038	22.40	7.002	31.46	0.796	18.69	7.935	20.06	18.36	47.26	51.0	0.10
	2:1	7.026	22.53	6.278	38.54	0.781	20.24	6.892	30.57	13.44	61.40	52.0	0.08
ZE:AL	1:1	7.975	12.07	8.022	21.47	0.861	12.06	8.403	15.34	18.18	47.79	52.3	0.08
	1:2	7.943	12.42	8.036	21.33	0.868	11.35	7.615	23.29	19.31	44.52	50.7	0.10
	2:1	7.923	12.64	8.106	20.65	0.824	15.84	6.551	34.01	15.17	56.43	52.3	0.08
MA:AL	1:1	6.058	33.20	7.808	23.56	0.917	6.29	7.519	24.25	24.54	29.52	51.3	0.09
	1:2	7.016	22.64	7.321	28.34	0.912	6.86	6.066	38.89	28.13	19.02	51.0	0.10
	2:1	7.002	22.80	7.169	29.82	0.913	6.69	7.356	25.90	22.62	35.03	52.0	0.08
MA:ZE	1:1	7.978	12.04	7.478	26.79	0.903	7.72	8.491	14.46	25.08	27.96	52.3	0.08
	1:2	8.051	11.24	8.256	19.18	0.911	6.90	8.212	17.27	27.17	21.94	53.0	0.06
	2:1	8.042	11.33	8.379	17.98	0.904	7.62	7.947	19.93	22.91	34.18	52.0	0.08
MA:SI	1:1	7.055	22.21	6.835	33.09	0.921	5.87	6.360	35.93	22.34	35.83	51.7	0.08
	1:2	7.034	22.44	7.956	22.12	0.903	7.70	5.247	47.14	23.45	32.64	51.3	0.09
	2:1	6.981	23.02	7.467	26.90	0.913	6.77	6.276	36.77	23.00	33.92	52.0	0.08
ZE:SI	1:1	6.981	23.03	7.388	27.67	0.717	26.78	7.284	26.62	11.28	67.60	52.3	0.08
	1:2	7.044	22.33	6.519	36.18	0.687	29.77	6.426	35.26	9.17	73.65	51.3	0.09
	2:1	6.031	33.50	7.208	29.44	0.697	28.81	7.078	28.69	9.86	71.68	52.7	0.07
AC:AL	1:1	7.055	22.21	7.491	26.66	0.609	37.79	4.344	56.24	5.53	84.12	51.3	0.09
	1:2	6.029	33.52	7.622	25.39	0.639	34.76	4.492	54.75	5.64	83.80	50.7	0.10
	2:1	5.984	34.02	7.083	30.66	0.597	39.04	4.184	57.85	4.53	86.99	50.7	0.10
AC:ZE	1:1	8.048	11.27	7.346	28.09	0.639	34.76	8.228	17.10	5.71	83.61	52.7	0.07
	1:2	7.045	22.32	8.023	21.46	0.658	32.75	5.688	42.70	5.67	83.71	53.0	0.06
	2:1	6.975	23.10	7.330	28.24	0.619	36.75	5.099	48.63	4.30	87.63	51.7	0.08
AC:SI	1:1	7.006	22.76	6.703	34.38	0.636	35.02	5.423	45.36	4.73	86.40	51.3	0.09
	1:2	7.002	22.80	7.468	26.89	0.686	29.94	4.749	52.16	5.70	83.63	50.7	0.10
	2:1	6.956	23.31	7.295	28.59	0.617	36.92	4.674	52.91	4.45	87.22	51.0	0.10
AC:MA	1:1	6.999	22.83	7.630	25.31	0.730	25.44	7.442	25.02	3.68	89.43	51.7	0.08
	1:2	7.038	22.40	7.845	23.21	0.810	17.20	7.718	22.25	3.63	89.58	52.0	0.08
	2:1	6.995	22.87	7.116	30.34	0.707	27.77	5.140	48.22	3.14	90.99	51.3	0.09

*Results are given as the mean of three individual tests of the oil treated by adsorption for 20 min at 80 °C. **Adsorbent combinations: SI = silica, AL = alumina, ZE = zeoliteNa4A, MA = magnesium silicate, AC = activated carbon.

oxidation products, including peroxides, aldehydes, ketones, hydroperoxides, polymers and oxidized monomers, can cause clinically harmful effects. The binary adsorbent combinations that significantly reduced the *p*-AV of P20 were SI:AL, ZE:SI, AC:SI, MA:SI, AC:AL, AC:MA (22.12-38.54 %). The binary adsorbents that were somewhat less effective were ZE:AL, MA:AL, MA:ZE, AC:ZE (17.98-29.82 %). Generally, the *p*-AV values for good quality oil should be less than 2.0. However, even after adsorbent treatment, the treated oil's *p*-AV values were much higher than 2.0. This result was due to the large amount of oxidation products present in the oil sample.

In general, large quantities of FFA formed as a result of hydrolysis, oxidation (due to free radical formation) and the cleavage of double bonds during frying. Some researchers consider FFA to be a good measure of frying oil quality. Others disagree, perhaps because FFA can react further to form volatile compounds and polymers. In this study, the FFA test was selected based on reports of its sensitivity in differentiating between various adsorbent treatments¹³. FFA present in the oil on the surface of a fried food offers a "sink" for oxygen in a food-containing package and can be used to predict the shelf life of the food before rancidity sets in¹. The properties of the SP20 that was treated with binary adsorbent combinations are shown in Table-2. For SP20, AC:AL (in a 2:1 ratio), AC:SI

(2:1) and AC:ZE (2:1) reduced FFA at a remarkably high rate, delivering 39.04, 36.92 and 36.75 % reductions, respectively. The binary adsorbent combinations of SI:AL, ZE:AL, MA:AL, MA:ZE, MA:SI, ZE:SI and AC:MA were less effective in reducing FFA.

Total polar compound (TPC) is a chemical index used to determine the degree of cumulative degradation of oil and it is an excellent predictor of frying oil quality. Total polar compound includes polar substances that occur in unused oils, such as monoacylglycerols, diacylglycerols and FFA and polar compounds that are formed during the heating of foodstuffs. Total polar compound is essentially the non-triacylglycerol fraction of the oil, which may be broadly grouped into polymerized and decomposed products based on molecular weight and polarity. The maximum permissible limit for TPC in frying oils is less than or equal to 25 %¹. As shown in Table-2, AC:AL provided the maximum removal of TPC (54.75-57.85 %), followed by AC:SI (45.36-52.91 %). The binary adsorbent combinations of SI:AL, ZE:AL, MA:AL, MA:ZE, MA:SI, ZE:SI, AC:ZE and AC:MA were less effective in reducing TPC.

Colour is one of the traditional methods used for assessing oil quality. Colour development tends to indicate oxidation, polymerisation and the formation of carbonyl compounds. Frying oil darkens with use and eventually affects the colour

of the fried product. Many researchers have reported colour as an important parameter for assessing the overall quality of oil¹³. Oil's colour increases dramatically during frying and is influenced by frying temperature, even though the quantity of chemicals causing the increase in colour is small¹⁴. Table-2 shows the Hunter colour value results obtained from samples of SP20 treated with various binary adsorbent combinations. The binary adsorbent combinations of AC:AL, AC:ZE, AC:SI and AC:AL were reasonably good at recovering the oil's colour (delivering lower TCD values).

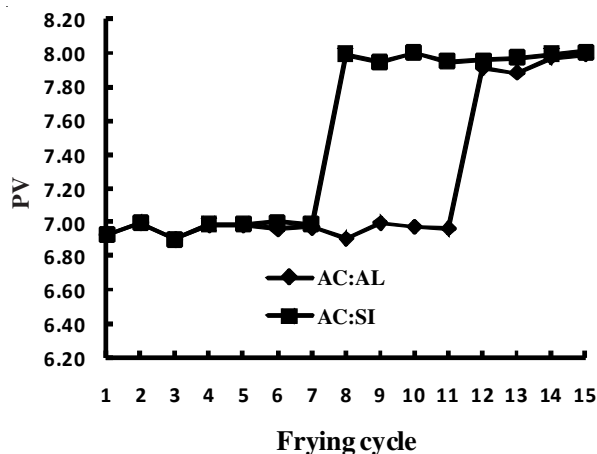
Changes in the viscosity of the oil resulted mainly from the formation of polymers during frying. The viscosity of the frying oil affects its tendency to stick to large cavities of the crust of the food product, such that a higher viscosity results in a larger volume of the oil ending up in the food product¹⁴. As can be seen from Table-2, all of the binary adsorbent combinations were rather ineffective at reducing viscosity. The results shown in Table-2 indicate that viscosity of the used, treated frying oil did not differ greatly according to the binary adsorbent used.

Adsorbent combinations were selected after each adsorbent was screening and ranked on the basis of its overall percentage improvement (PI %) values across all of the analysis parameters. The binary adsorbents AC:AL and AC:SI (both in a 2:1 ratio) provided a significant improvement in PV, FFA, TPC and colour. The AC adsorbent was found to be very successful in recovering PV, FFA, TPC and colour due to the action of van der Waals force-dominant adsorption on a non-polar surface with a high surface area. Polarisability is the main factor governing the magnitude of the van der Waals energy and it is roughly proportional to the molecular weight¹. Lewis acid sites are usually abundant on AL, such that the surface acidity of AL is its most important property for adsorption. SI's ability to remove other decomposition products present in frying oil can be attributed to its polar nature, which selectively separates particles on the basis of their molecular weight and high surface area, thus entrapping decomposition products of a higher molecular weight. Hence, AC:AL and AC:SI, both in a 2:1 ratio, were selected as the binary adsorbents to be reused for 15 consecutive fryings.

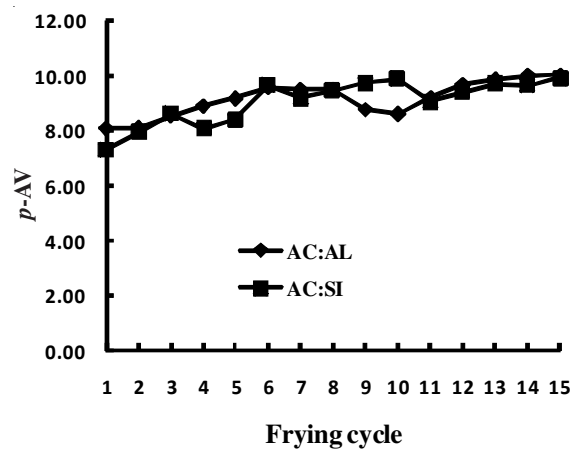
The changes in the oil parameters after being treated with reused binary adsorbents each frying cycle (15 times) are shown in Fig. 1. We found that parameters of the oil samples treated with the two reactivated binary adsorbent combinations rose almost in parallel in later instances of frying. The binary adsorbents AC:AL and AC:SI, both in 2:1 ratios, thus provided similar improvements in the oil parameters (*p*-AV, FFA % and TPC). The binary adsorbent combination of AC:AL showed a significantly greater reduction in PV and viscosity than AC:SI, while AC:SI provided colour bleaching (TCD) better than that achieved by AC:AL.

Conclusion

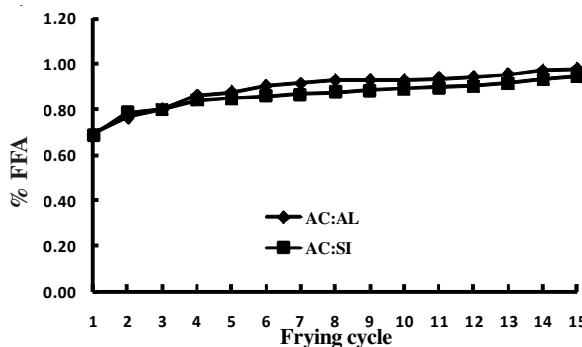
The treatment of used frying palm oil with binary adsorbent combinations could significantly improve the quality of frying oil, either by extending the frying life of the recovered used oil or by slowing down the rate of deterioration of fresh oil. Among the binary adsorbents studied, AC:AL and AC:SI were selected for their greater efficacy in improving PV, *p*-AV, FFA,



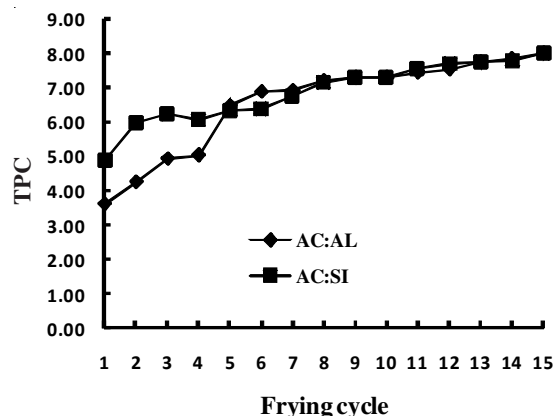
(a)



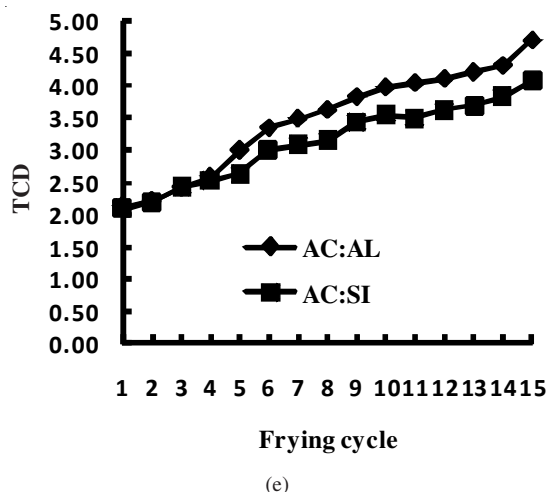
(b)



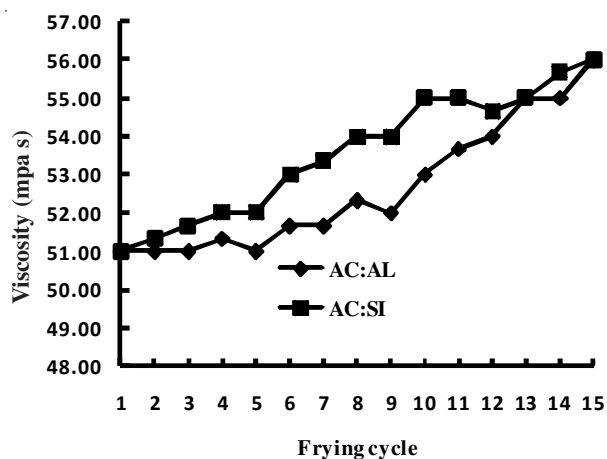
(c)



(d)



(e)



(f)

Fig. 1. Oil parameters after being treated with reused binary adsorbents each frying cycle. \blacklozenge , binary adsorbent combinations of AC:AL (2:1); \blacksquare , binary adsorbent combinations of AC:SI (2:1) where (a) PV, (b) *p*-AV, (c) FFA, (d) TPC, (e) colour and (f) viscosity parameters

TPC, colour and viscosity parameters in oil. The two binary adsorbent combinations (AC:AL, AC:SI) gave rise to almost parallel trends at later stages in the frying process. The binary adsorbent composition of AC:AL provided a significantly greater reduction in PV and viscosity than AC:SI. Treatment with AC:AL (ratio of 2:1) thus proved to be most effective at reducing oil decomposition products in the used frying palm oils. This binary adsorbent may be particularly useful in extending the life of frying oils.

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