Refuse-derived plastics from waste polystyrene and recovered deep-fried oil 1.Introduction Disposable polystyrene utensils have been pop u lar ly used in Taiwan for the past two de cades to pre vent the transmission of hepatitis. The use of these utensils has increased over the years and is expected to continue to increase in the future. However, the increasing quantity of municipal sol id waste and lack of land fill space and incinerators has become a se ri ous environmental problem. Deep-fried food is fa vored in most Asian countries, but eating too much such food may cause my o car dial impaction, venous thrombosis, or hy per ten sive car dio vas cu lar disease because the cook ing oil has been oxidized and poly mer ized under high temperature. Thus, the disposal of over-used deep-fried oil is also an important en vi ron men tal issue in Taiwan and most oriental countries. Waste-to-source management is the best pol i cy for solving environmental problems. To decrease the pollution in sewage wastewater from over-used deep-fried oil, the women's league in Taiwan ad vo cates its recycling to manufacture heavy-duty soaps(1). Although waste-to-source management is the best recycling protocol for re cov er ing deep-fried oil, it creates alkali and glyc er ol pollutants in the wastewater. Since recycling should not create en vi ron men tal problems, man u fac tur ing processes, en er gy consumption, and pollution release should be evaluated thoroughly. In this study, an environmentally acceptable pro cess for deriving a plastic from waste poly sty rene foam and recovered deep-fried oil was in ves ti gat ed as an alternative treatment technique for both wastes based on their chemical and physical properties. Sty rene monomer was selected as the reaction solvent to dissolve waste polystyrene foam, and the re cov ered deep-fried oil was used as a plas ti ciz er in the refuse-derived plastic. Ap pro pri ate amounts of me th yl ethyl ketone per ox ide (MEKPO) was added as a reaction initiator and cobalt-naphthenate as a promoter. After thor ough ly mix ing the polymer so lu tion and those additives, the reaction mixture was then poured into a processing mold.(2-5) To obtain an optimum formula, parameters that affect the process, such as viscosity, ease of operation, reaction time for hardening, and the phys i cal and chemical properties of the derivedproducts were studied thoroughly. Because the re ac tion can be achieved at room temperature and all of the com po nents are exhausted in the man u fac tur ing process, the production of refused-de rived plastics con sumes less energy and does not release new pollutants. Thus, this procedure con forms to recycling regulations. 2. Experimental Section Equipment: A Brookfield Synchro-Lectric Vis com e ter (Brookfield Engineering Lab. Inc.,

Stoughton, Mascachusetts) was used to detect the viscosity of oils, and polymer solutions. A cake mix er (Tatung, Taipei, Taiwan) was used to mix the com po nents of the formula. A self-made glass process ing mold was used for completing the reaction. The HPLC used to determine the sty rene content in the leaching so lu tion was a LC-9A system (Shimadzu, Kyoto, Japan) equipped with a Rheodyne 7125 in jec tion valve (20 µL sample loop) and a reversed phase Supelcosil LC-18 col umn (25 cm x 4.6 mm id, 3 µL) (Supelco Inc, Bellefonte, PA). A Waters 484 tunable ab sor bance detector (Waters, U.S.A) and a Shimadzu C-R6A Chromatopac integrator were used to detect and obtain a chromatogram. An Universal Materials Testing Instrument (Zwick model 1474) was used to test the physical properties of tensile strength, flexile strength, and stress tolerance of the refuse-derived plastic. Chemicals: Reagent-grade potassium iodide, so di um thiosulfate, and styrene were purchased from RDH. Industrial-grade methyl ethyl ketone per ox ide and cobalt-naphthenate were obtained from Deuchem Co. (Taipei, Taiwan). Acetonitrile is HPLC grade obtained from Mallinckrodt, Inc. (Kentucky, USA). Collection of wastes: 50 polystyrene lunch-box es were washed with water, dried, and crushed for studies. 3 liters of recovered deep-fried oil was col lect ed from the campus student restaurant. Formulation process: Styrene was selected as the reaction solvent to dissolve the crushed polystyrene. After mixing the polymer solution, the over-used deep-fried oil, methyl ethyl ketone peroxide, and cobalt-naphthenate thoroughly, the reaction mix ture was then poured into a process ing mold for complete reaction at room temperature. All of the experiments were per formed in a hood. Leaching test for refuse-derived plastics: The refuse-derived plastics were made from var i ous formulas. The crushed refuse-derived plastics were soaked in bottles of 200 mL water overnight. After being filtered, the leachate solution was in ject ed into the

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HPLC analyzer to determine styrene concen tration. For comparison, a commercial poly sty rene foam prod uct was also crushed and weighed, and then soaked in 300 mL of water overnight. The leachate so lu tion was also an a lyzed by HPLC to determine sty rene concentration. The eluent used in the HPLC analyzer was an 80% aqueous ac e to ni trile solution at pH 6.0. Chemical durability test: Several pieces of refuse-derived plastics and a commercial poly sty rene plas tic were soaked in concentrated HCL, 30% NaOH, and ethyl acetate solvent overnight for the chemical durability test. Physical property test: (6-7)Refuse-de rived plas tic was cut into pieces of 25 mm (width) x 4.0-4.3 mm (thickness) for 18% recovered oil content, and 24.8-25 mm (width) x 3.6-4.3 mm (thickness) for 15% recovered oil content. These pieces of refuse-de rived plastics were tested by ASTM D-638, D-790, and D-695 test methods (Universal Ma te ri als Testing Instruments) for phys i cal prop er ties such as tensile strength (Young's Modulus), maximum force, max i mum (flexile) stress, and break force, stress tolerance, com pres sion section of maximum force, com pres sion sec tion of break,

and tensile strength (Young's Modulus), 3. Results and Discussion Properties of recovered deepfried oil In order to understand the physical and chem i cal properties of recovered deep-fried oil, the vis cos i ty and iodine number were tested and com pared with those of fresh cooking oil. (8-9)Table 1 lists the vis cos i ty and iodine number of recovered deep-fried oil and fresh cooking oil. As shown, the vis cos i ty of recovered deep-fried oil is higher than that of fresh cooking oil, and the iodine num ber of re cov ered deep-fried oil is much lower than that of fresh cook ing oil. This indicates that some polymer ization occurred in the oil during the deep-fry ing process, which increased the oil viscosity. Furthermore, oxidation or reduction may have oc curred at the unsaturated double bond of the oil to decrease the iodine number. Both changes fa vor the dryness of oil. Thus, the re cov ered deep-fried oil has the potential to be reused. Dissolution of waste polystyrene Because the styrene monomer was selected as the reaction solvent to dissolve waste-polystyrene, its dissolution capacity was tested. In the test, 150 g of styrene was used to dissolve various amounts of waste polystyrene. Fig.1 il lus trates the dis so lu tion capacity of styrene sol vent on polystyrene foam, showing that the vis cos i ty increases with the dis solved quantity of polystyrene and maximizes at 150 g of styrene. After the maximum dissolution, the styrene sol vent loses the solvent character. The dis so lu tion capacity of styrene to waste poly sty rene foam is 150 g /150 g. Hence, an equal amount of styrene monomer is required to dissolve polystyrene. Formulation tests Based on the capacity of the reaction sol vent to dissolve waste polystyrene foam, seven for mu las at various gradients were examined to observe fac tors that affect the processing parameters, such as viscosity, ease of operation, reaction time for hardening, and the physical and chemical proper ties of the derived-products. Table 2 lists the formulas and the processing properties. As shown, the content of recovered oil could not reach 25% due to miscibility and could not be lower than 15% to keep the products' rigid i ty and flexibility. Therefore, the recycled fried-oil was best controlled within a range of 18-21% in the de rived plastic based on its drying time, homogeneity, rigidity, and flexibility. Effect of cobalt-naphthenate on drying time Cobalt-naphthenate is generally used as a dry ing agent in paint drying processes and as a cat a lyst in polystyrene manufacturing processes. Thus, the ad di tion of cobalt-naphthenate in the formula was examined to obtain an acceptable drying time. For mu la No.6 40.25% recycled polystyrene, 40.25% styrene monomer, and 1% MEKPO in Table 2 (Formula 6) was tested with various con cen tra tions of cobaltnaphthenate. The results are listed in Ta ble 3. It is obvious that the higher the amount of cobalt naphthenate in the formula, the shorter the drying and hardening time for the refuse-derived plastic. The reaction takes about eight to twelve hours to complete depending upon the amount of drying agent in 1-0.5%. These times are acceptable to the poly sty rene and related industries

Effect of MEKPO on hardening time MEKPO is used as a catalyst in poly sty rene man u fac tur ing processes. In general, a high er con tent of MEKPO shortens the reaction time and de creas es the degree of polymerization, which could worsen physical properties. However, a low er amount of MEKPO increases the hardening time and prevents drying. Thus, the effect of MEKPO on the hard en ing time of recycled plastics was in ves ti gat ed based on Formula 6 in Table 2; the re sults are shown in Table 4. As predicted, the higher the amount

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of MEKPO in the formula, the shorter the hardening time for the refuse-derived plastic. The reaction takes about ten to twelve hours to com plete for a pro mot er content between 1.0% to 1.5%. These are acceptable times to the polystyrene and related in dus tries Leaching test for styrene residual Although the reaction solvent is de signed to dis solve recycled polystyrene and complete the poly mer iza tion reaction, trace amounts of styrene mono mer might still exist in the refuse-derived plastic. The level of styrene residuals will in flu ence the ap pli ca tion of the refuse-derived plastics. Thus, a leaching test for styrene in water was conducted. Refusede rived plastics produced from For mu las5-7, were leached in 200 ml of water, and a com mer cial poly sty rene product was leached in 300 ml of water overnight. After being filtered, the leachates were injected into the HPLC/UV analyzer to de ter mine the styrene concentrations in the leachates and then evaluate the relative amount of styrene res i due in each formula and commercial product. (10) Fig. 2. is the HPLC chromato gram of styrene in the leachate solution. In the chromatogram, peak 1 is the solvent front, and peak 2 corresponds to the styrene. In or der to evaluate the styrene content in individual leachate solutions, the calibration plot of styrene was constructed, as shown in Fig. 3. The cal i bra tion plot is linear in the concentration range of 1 μ g/L to 10 μ g/L with a linear correction co ef fi cient of 0.9994. The linear relationship is very good and can be used to quantify the styrene con tent in leachate solutions. Table 5 lists the relative con tents of styrene in the formulas and the com mer cial product. The results show that, the sty rene residue in the refuse-derived plastics were about two times of that in the commer cial product. Com par ing the styrene residue in the three tested formulas, the plas tic dericed from formula 5 uses less styrene mono mer than the other two but con tains a higher amount of styrene residue than the others. The rea son for this is that the high er con tent of recovered oil in the reaction mixture pre vent ed completion of the reaction; hence, a for mu la with a high content of recovered oil pro duced a great er amount of sty rene residue in the refuse-de rived plastic than oth er formulas. Chemical durability test A comparison of the proposed refuse-de rived plas tic with a commercial polystyrene plas tic for chem i cal durability indicates that the refuse-de rived plas tic had as much resistance to concentrated. HCl as the commercial product, but both were not re sis tant to acetic acetate. In 30% NaOH solution, a low er level of saponification occurred on the sur face of the refusederived plastic. Physical properties of the refuse-derived plastics Test results for physical properties, such as ten sile strength, flexile strength, and stress tol er ance of the refuse-derived plastics using the ASTM

D-638, D-790, and D-695 test methods are listed in Table 6. The flexile strengths of the refusederived plas tics ranged from 58.2-59.4 Kg/cm2 for 18% re cov ered oil and from 77.9-80.9 Kg/cm2 for 15% re cov ered oil. It is obvious that increased addition of re cov ered oil decreases the flexile strength. This property is the same as that of Furan resins and ther malplas tic polyurethane, which are in the range of 42 Kg/cm2 to 632 Kg/cm2, and 50 Kg/cm2to 630 Kg/cm2, respectively. The stress tolerance of the refuse-derived plastics is in the range of 55.8-57.6 Kg/cm2 for 18% re cov ered oil, and in 76.2-78.4 Kg/cm2 for 15% re cov ered oil. It is obvious that in creas ing the ad di tion of recovered oil also de creas es the stress tolerance. This range is similar to that of soft poly-vinyl-chloride resins, which is 60 Kg/cm2to 120 Kg/cm2. With regard to the flexile strength of the refuse-derived plastics, Young's Modulus for plas tics with 18% recovered oil and 15% re cov ered oil range from 68.4 to 88.2 Kg/mm2 and 78.2 to 82.2 Kg/mm2, respectively. These val ues are similar to those for HDPE (40-130 Kg/mm2), acetyl cel lu lose (50-280 Kg/mm2), ethyl cellulose (70-210 Kg/mm2), ther mal plastic poly ure thane (70-250 Kg/mm2), polyvinylenechloride (40-60 Kg/mm2), ionomer (SURLYN-A) (10-40 Kg/mm2), PTFE (40 Kg/mm2), and PVDF (80 Kg/mm2).4.Conclusion In this study, waste polystyrene foam and re cov ered deep-fried oil were recycled and reused to produce a refuse-derived plastic comparable to some commercial products. Because the reaction can be achieved at room temperature and all of the com po nents are exhausted in the reaction, the production of refuse-derived plastics consumes less energy and does not release any pollutant. Thus, this procedure conforms to recycling regulations. It can be use as an alternative technique to solve pol lu tion problems related to polystyrene foam waste and oil from deep-fried cooking processes. In the future, I would like to continue my study in the

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ap pli ca tion of this technique, to materials such as wall or floor paneling, decoration utensil, casts, boxes, and trash cans. **5**. Acknowledgments The author would like to thank the Na tion al Sci ence Education Museum of R.O.C. (Taiwan) for fi nan cial support, the chemistry department of Na tion al Chung-Hsing University, and the research cen ter of Nun-Ya Plastic Co. for assistance with chem i cal analysis. **6**. Bibliography 1. M.-Y. Wang, K. -D. Kou, C. -S. Lai, Y. -J. Hwang, Green Proposal of Women league in Taiwan, 145 (2000) 12-16. 2. S. -W. Tsai, "Organic Chemistry", (1997), Dong -Ta Press, Taipei, pp.37-42. 3. S. -W. Tsai, "Organic Chemistry", (1997), Dong -Ta Press, Taipei, pp.111-121.

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Table	2.	Components	in	test	formula	

Formula-	Waste	Styrene	Recovered	MEKPO	Cobalt-	Product
tion No.	Polystyrene	solvent	oil		naphenate	Characters
1	30%	30%	40%	0%	0%	A
2	34.25%	34.25%	30%	1%	0.5%	B
3	36.75%	36.75%	25%	1%	0.5%	C
4	38.25%	38.25%	22%	1%	0.5%	D
5	38.75%	38.75%	21%	1%	0.5%	E
6	40.25%	40.25%	18%	1%	0.5%	F
7	41.75%	41.75%	15%	1%	0.5%	G

a: Bad miscibility, recovered oil was excluded from pol

B: Separate into two layers

C: Part of oil floats on the polymer produ

D: Homogeneous, drying time OK, polymer product is elastic

E: Homogeneous, better drying time, polymer product is elastic and flexi

F: Homogeneous, better drying time, polymer product is elastic and flexibl G: Homogeneous, fast dry, polymer product is elastic and flexible

Publisher, Tainan, pp.182-188.

Table 1. Viscosity and iodine number of fresh oil and recovered deep-fried oil

[Formula 9

Table 3 Effect of cobalt-naphthenate on harding and drying time						
Formula No 6	Cobalt-naphthenate.	Drying time				
1	0.2%	20 hours				
2	0.5%	12 hours				
3	1.0%	8 hours				

	Viscosity	Viscosity	Iodine number	Iodine number
	Fresh oil	Recovered oil	Fresh oil	Recovered oil
	70 (C.P.)	106 (C.P.)	127.9	48.2
	72	106	128.4	51.3
	72	108	125.2	49.1
age	71.3	107	127.1	49.5

Table 5. Relative amount of styrene residuals in refuse-derived plastics and commercis polystyrene product

0.2206 g

1.39 μg/L 0.120% 0.2430 g

300 mL 0.53 μg/L

0.0659

Table 4	Effect of	f MEKPO	on hardening	and drying	time

Table 6. Physical properties of refuse-derived pla

		Weight	0.3548 g	0.2894 g	
MEKPO	Drying time	Vol. of water	200 mL	200 mL	
0.5%	10 hours	Analytical results	2.5 µg/L	1.99 µg/L	
1.0%	12 hours	Relative residu.	0.141%	0.135%	
1.5%	24 hours	in samples			

Test pieces: 80 nm x 25 nm x 4 nm (L x W x D)

Speed: 1.3 mm/min

E-value: 1 - 2 Kg

Machine: Zwick 1474

FIGURE CAPTIONS

Fig.1. Dissolution capacity of styrene solvent on polystyrene foam.

Fig.2. HPLC chromatogram of styrene in leachate solution

Peak 1: solvent front; Peak 2: styrene

Units of maximum flexiel stress and break stress are Kg/cm²

E-value: Young' s modulus, in Kg/mm²

Fig.3. Calibration plot of styrene

Oil %	Thick	Width	Maxi.	flexural	Break-	Break-	MF-	Break-	E-
	(mm)	(mm)	Force	(MF)	force	stress	compre.section	compre.section	Value
			(Kg)	stress	(Kg)				
18%	4.2	25.0	2.8	58.2	2.6	55.8	0.8 mm	0.9 mm	88.2
18%	4.3	25.0	2.9	59.4	2.7	57.6	0.9	0.8	81.6
18%	4.0	25.0	2.8	59.2	2.6	57.4	0.8	0.8	77.6
18%	4.0	25.0	2.7	58.4	2.5	56.2	0.7	0.9	72.5
18%	4.2	25.0	2.9	58.6	2.8	56.6	0.8	0.7	68.4
15%	4.1	24.9	3.4	80.9	3.3	77.1	1.1	1.1	82.2
15%	4.3	24.9	3.1	79.2	3.2	76.2	0.9	0.9	78.8
15%	3.7	25.0	3.3	78.4	3.3	78.4	1.0	0.9	78.2
15%	3.6	24.8	3.1	77.9	3.0	77.4	1.1	1.0	80.2
15%	3.8	25.0	3.2	80.4	3.1	77.8	1.0	0.9	79.4