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A Modeling Comparison Studies for Thermo-Mechanical and other Properties of RHDPE and RLDPE Wastes

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ABSTRACT

A recycled waste plastic (recycled high density poly ethylene RHDPE and recycled low density poly ethylene RLDPE) are exposed to environmental conditions during the usage for many years ago. Also the chemical contaminants in the internal composition had effects on the thermo-mechanical and other properties for these wastes.

Then weathering effect data are examine for both locally and international wastes on their thermo-mechanical and chemical properties such as (Tensile strength, modulus, elongation, impact and permeability) respectively.

Afterward different mathematical software models are applied to analysis these weathering – properties data in order to estimate the more effective properties that changed by these weathering conditions such as (concentration of contaminant, time, temperature, thickness of specimen, length of spectra, basic property).

The results shows that a multi-polynomial model has a best fit for most or several of properties to active weathering variables, also gave a vary residual and deviation than experimental analyzed data for both sources of wastes local and international RHDPE and RLDPE. Also results of thermo-mechanical and chemical properties prove that both tensile strength and modulus of elasticity thermo-mechanical properties and permeability / length of spectra chemical property were given a high quality of correction and fitting factor from 93-99 %, with less deviation and residual function was produced. And analyzed weathering properties of RHDPE gave a best fit than RLDPE; all of them fitted the mathematical software model below:

$$y_{model} = a + bx_1 + cx_2 + dx_1^2 + ex_2^2 + fx_1x_2 + gx_1^3 + hx_2^3 + ix_2^2 + jx_1^2x_2 \quad \ldots(1)$$

Where:

$a, b, c \ldots J$ = coefficient of the best fit model.
x_1 = concentration of contaminants.
x_2 = time of aging.

Keywords: High Low Density Polyethylene, Weathering, Mechanical Properties, Modeling.

نمذجة دراسات مقارنة للخصائص الثرمو- ميكانيكية وخصائص اخرى للبولي اثليين عالي وواطيء الكثافة المعاد

الخلاصة

أن المـواد البلاستيكية المعـادة تتعـرض للتغيـرات الجويـة المحيطـة بهـا نتيجـة الاسـتخدام لعـدة سنوات. بالأضـافة الـى تـأثير الشـوائب الكيمياويـة نتيجـة معاملتهـا إثنـاء عمليـات التصـنيع والصـب وخصوصاً على الخصائص الثرمو-ميكانيكية والخصائص الأخرى.

لذلك تم تفحص العديد من البيانات حول تأثير ظروف التجويه لنماذج محلية وعالمية لمواد معادة علـى خصائصـئها الثرموميكانيكـة والكيمياويـة مثـل (قـوة الشـد، معامـل المرونـة، الأسـتطالة، قـوة الصدمة،والنفاذية)على التوالي.

فيمـا بعـد تـم تطبيـق مختلـف المـوديلات الرياضـية الالكترونيـة لتحليـل تلـك البيانـات (ظـروف التجوية) لتحديد اكثر هذه الخصائص تاثرا اي تغيرا مع تلك الظروف (ظروف التجوية مثل تركيز الشوائب، زمن التعرض للظروف البيئية القاسية، درجة الحرارة، سمك العينة او الشريحة، الطول الموجي للأشعة المطبقة، الخاصية الاساسية).

وأثبتت النتائج الرياضية التحليلية بواسطة الحاسوب انطباق الموديل المتعدد الدوال علـى اغلب الخصائص المقاسة / متغيرات ظروف التجوية المطبقة حيث اعطى هذا الموديل النتائج اقل انحرافاً للقيم العملية عن النظرية وانطباقاً اكثر بين النوعين من البلاستيك المعاد المحلي والعالمي الواطئ والعالي الكثافة.واكدت نتائج كل من الخصائص الثرمو-ميكانيكية والكيمياوية انطباقاً اكثر لخاصتي الشد والمرونـة والخاصـية الكيمياويـة وهـي علاقـة النفاذيـة / الطـول المـوجي للاشـعة الجويـة حيـث اعطت معامل تصحيح عالي النوعية واقل انحرافاً من 93-99 %.اضافة الى ذلك علاقة الخصـائص الثرمو-ميكانيكيـة والكيمياويـة للبولـي اثيلـين عـالي الكثافـة (PETH) كانـت اكثـر انطباقـاً مـن النـوع الأخـر مـن المعـاد البـولي اثيلـين الـواطئ الكثافـة(PETL) واعطـى الكـل انطباقـاً للموديـل الرياضـي التالي:

$$y_{model} = a + bx_1 + cx_2 + dx_1^2 + ex_2^2 + fx_1 x_2 + gx_1^3 + hx_2^3 + ix_2^2 + jx_1^2 x_2 \quad ..(1)$$

INTRODUCTION

Recycling is an expanding area of chemical industry in general, plastic recycling and waste management in particular is being closely being examined in academic commercial organizations and governmental institutions. Finding suitable solutions could lead to the recycling of potentially hazardous materials on the other hand production of acceptable commercial products with little or no outlay in raw material. A precursor to recycling is to understand the effects of chemical contaminants on the properties of both RHDPE and RLDPE and eventually how these effects can be overcome to successfully reuse contaminated RHDPE and RLDPE [1].

However in the regeneration process some problems have still not been resolved, such as: the sorting of the plastics with optimal purity over cost ratio, their cleaning, the characterization of the regenerated product before it is sold, and the market for the recycled products. Both the sorting and characterization of the polymer are obligatory steps of the recycling process: the first because the recycling blend of polymer does not lead to satisfactory products and the second, because the final user of the regenerated material must be informed of the real quality of the product used [1].

All the more as it might be hazardous to re-use some blends such as PVC and PET blends [1- 3].

RHDPE and RLDPE consumption continuous to grow annually, with products substitution and potential new applications increasing volume sales growth. Such as pipes segments, bottles of pipsi and milk. Where HDPE substitution into juice and milk packaging market is likely to continue as high density bottles replace glass and Tetra-Pak bricks. For replacing metals in automotive fuel tank, metal cans, large industrial container and house hold fuel tanks is also likely to support HDPE and LDPE demand in the coming years [1, 2, and 4]

D.S. Achilias has been studied the recycling of either model polymers or waste products based on low-density polyethylene (LDPE), high-density polyethylene (HDPE) or polypropylene (PP) is examined using the dissolution/ reprecipitation method, as well as pyrolysis. In the first technique, different solvents/non solvents were examined at different weight percent amounts and temperatures using as raw material both model polymers and commercial product (packaging film, bags, pipes, food-retail outlets) .Some authors were studied the change in mechanical properties of R-polyethylene after exposure to artificial weathering then check their mechanical weathering properties [5-10]. Others were proposed a mathematical model to predict the behavior of Thermo-mechanical properties of LDPE [11]. In the other hand many of researchers were studied the effect of many stabilizers on the structure and thermo-mechanical properties of LDPE then show their effect of Cr2O3 on the optical properties of LDPE [12, 13]. Apparently, studied of literature review indicated that many of inorganic pigments such as Iron oxides, Chromic oxides and Titanium oxide are widely used as stabilizer in plastic industry (HDPE and LDPE) [14,15,16].

Aim Of The Research

The use of recycled plastics in packaging is growing around 14 %, as year as a result of increased demand and collection growth of recycled materials is due to both legislative mandate and technology advancements.

An interesting sorting characterization data for this study was used to compare the effect of chemical contaminates with other weathering variables such as (time of aging, temperature, thickness of specimen, length of spectra, basic property) on the Thermo-mechanical and chemical characteristics such as (tensile strength, modulus of elasticity, impact strength, elongation, permeability)

for both types of sources locally and international polyethylene wastes (RHDPE and RLDPE).

Also state which one or several of these sorting and characterization properties had more effects by the above weathering conditions. Then design a mathematical model for the analyzing properties with more economical, fitting and applicable, also with high quality for correction factor and less residual deviation between experimental and theoretical one.

On the other hand state which one or several analytic properties were used to specify and modify these wastes in an industrial process applications.

Theoretical Background Data

The Thermo-mechanical and chemical properties for both polyethylene wastes (RHDPE and RLDPE) data had been studied at different weathering conditions (concentration of chemical contaminant, temperature, time of aging, thickness of specimen, length of spectra and basic property) with a great detail.

As a result, a variety of available software models were used to analysis and describe these properties for Thermo-mechanical properties / (concentration of contaminants, time, basic property in addition chemical properties) / time, concentration of contaminates, thickness of specimen, length of spectra. By the use of experimental data produced for locally and international wastes of RHDPE and RLDPE respectively in order to arrive an optimal software model with best fitting and less deviations for all properties data from both type of sources .

Then related a comparison and mixing model between locally and international PE wastes to give an accurate, simplest and best fitting software model, also stated which of these sorting properties are basic and specify property for modification these wastes and re-use them in different industrial process applications [17-21].

EXPERIMENTAL PROGRAMS

Materials

The source data for Thermo-mechanical and chemical properties of both RHDPE and RLDPE wastes produced by national and international researchers. Also the source of both RHDPE and RLDPE wastes were collected from local waste bottles for of both Pipsi and milk for international one. Then a modern modeling software programming was use and updating continuously from a web site Internet system to give an economic and simple model to analysis these sorting properties / weathering condition from both sources of PE wastes locally and internationally.

Procedures

The case problem was a negative effect of hazard polyethylene wastes on the environment and public-health then a theoretical software programs were used to study the effect of different weathering conditions (concentration of contaminate, temperature, time of aging, thickness of specimen, length of spectra, and basic property) on both Thermo-mechanical properties (tensile strength, modulus of elasticity, impact strength, and elongation) and chemical property of permeability to design an optimum software model on both PE wastes (RHDPE and RLDPE) from both sources locally and internationally.

And this experimental program was achieved by several steps: firstly, classified a details data in two cases Thermo-mechanical and chemical properties for both locally and international PE waste (RHDPE and RLDPE). Secondly, sketched the experimental data details as a comparison between both source data properties for PE wastes (RHDPE and RLDPE).

RESULTS AND DISCUSSION

This part of research consists of measuring many properties separately and in linked as shown below:

Thermo- mechanical properties/ tensile strength

The experimental data for both PE wastes (RHDPE and RLDPE) indicated that an increasing in the concentration of contaminates cause an increasing of tensile strength values at different weathering time with less deviation between result at all weathering time 150, 250 hr, also the values of this property was higher for locally source in RHDPE waste and lower for international RLDPE one as shown in Figures (1-4).and another results of fitting are shown in Table (1) for both types PE wastes from both sources locally and internationally one respectively.

Table (1) shows the coefficients values for optimum model of tensile strength for both RHDPE and RLDPE wastes.

Coefficient	Value	
	RHDPE	RLDPE
a	17.730	13.55
b	1.109	1.194
c	$1*10^{11}$	$-1*10^{11}$
d	$-5.109*10^{-2}$	$-1.4*10^{-2}$
e	$-1*10^{9}$	$1*10^{9}$
f	$9.254*10^{-4}$	$1.73*10^{-3}$
g	$1.736*10^{-3}$	$6.07*10^{-3}$
h	$2.7*10^{6}$	$-4.07*10^{6}$
i	$2.2*10^{-6}$	$-1.14*10^{-5}$
j	$-5.8*10^{-6}$	$-6.98*10^{-5}$
R^2	0.9749	0.9559
V (%)	97.49	95.59

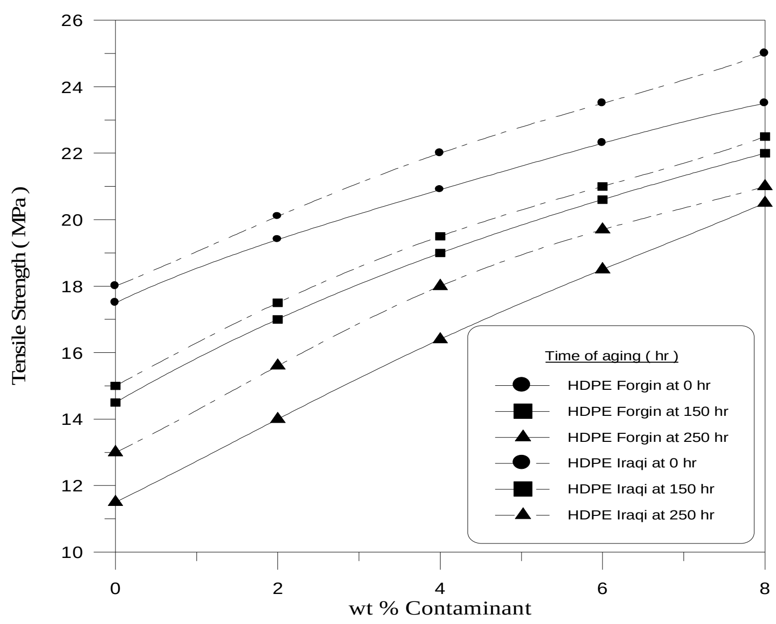

Figure (1) The experimental data for tensile strength properties for RHDPE.

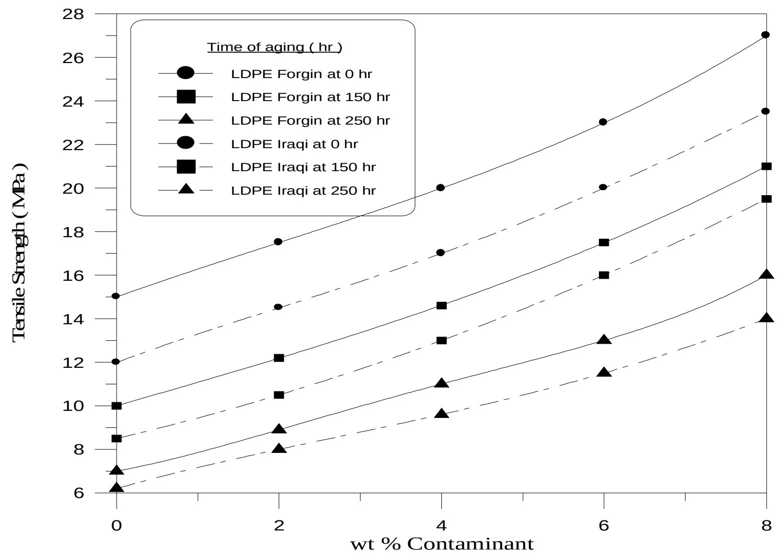

Figure (2) Shows the experimental data of tensile strength for RLDPE.

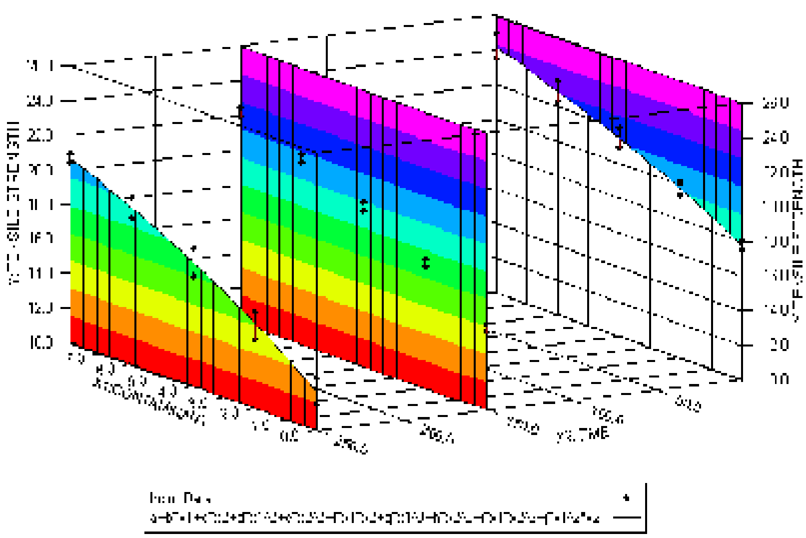

Figure (3) Indicates the theoretical fit model of data for RHDPE.

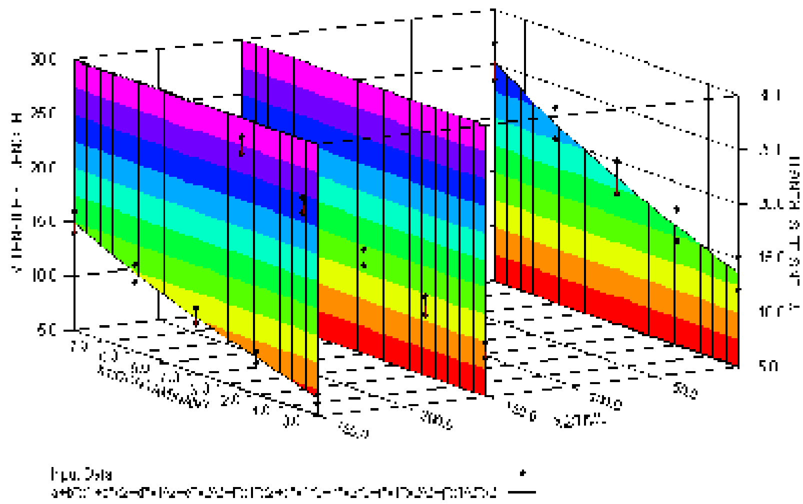

Figure (4) Indicate a theoretical model of data for RLDPE for both locally and international waste.

Thermo-mechanical properties/Impact Strength

The experimental data for both PE wastes (RHDPE and RLDPE) indicated that an increasing in the concentration of contaminates cause a decreasing of impact strength values at different weathering time with higher deviation between result at 250 hr, also the values of this property was higher for international source in RHDPE waste and locally source for RLDPE one as shown in Figures (5, 6).

Afterward an application of different software model program were achieved for both waste types (RHDPE and RLDPE) and sources (locally and internationally), which gave an optimum multi-polynomial software model of high correction factors for RHDPE 79% and low correction factor for RLDPE 30% and less deviation and residual for RHDPE and RLDPE at range (0.008-0.02) % as shown in Figures (7,8). The results of coefficients values and other fitting results were shown in Table (2).

Table (2) The coefficients values for fitted impact property model for both wastes (RHDPE and RLDPE).

Coefficient	Value	
	RHDPE	RLDPE
a	0.215	0.13
b	$-1.34*10^{-2}$	$-5.6*10^{-3}$
c	$-4.7*10^{8}$	$-2.6*10^{9}$
d	$5.6*10^{-4}$	$-2.3*10^{-4}$
e	$5*10^{6}$	$2.7*10^{7}$
f	$2.85*10^{-5}$	$1.39*10^{-5}$
g	-1.77	$1.37*10^{-5}$

h	**$-1.2*10^4$**	**$-6.9*10^9$**
i	**$7.95*10^{-9}$**	**$-8.8*10^{-8}$**
j	**$-1.59*10^{-6}$**	**$2.56*10^{-7}$**
R^2	**0.97106**	**0.30047**
V (%)	**97.106**	**30.047**

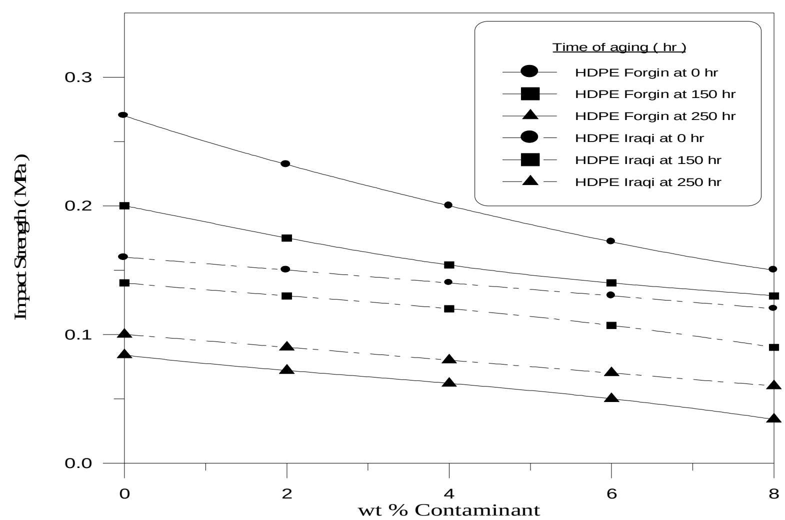

Figure (5) Indicates the experimental data for impact property for both locally and international RHDPE wastes.

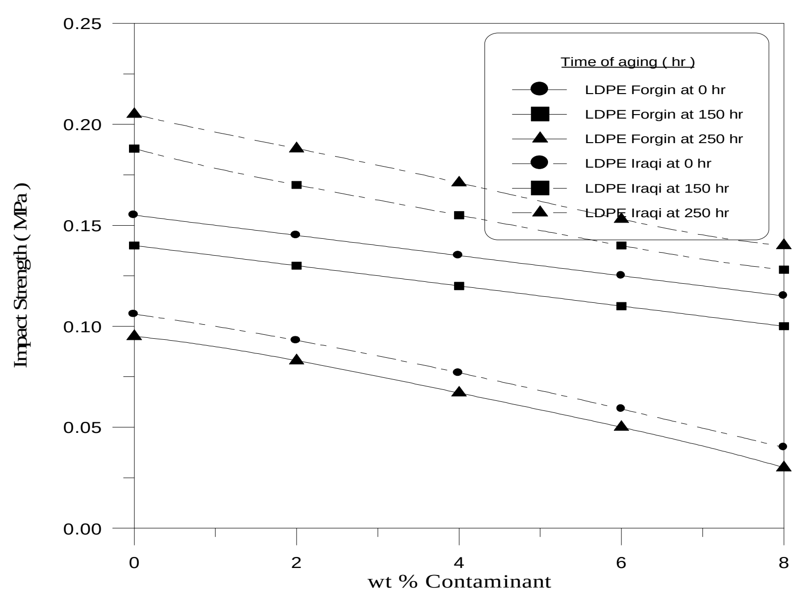

Figure (6) Indicates the experimental available data for RLDPE both locally and international source for impact property.

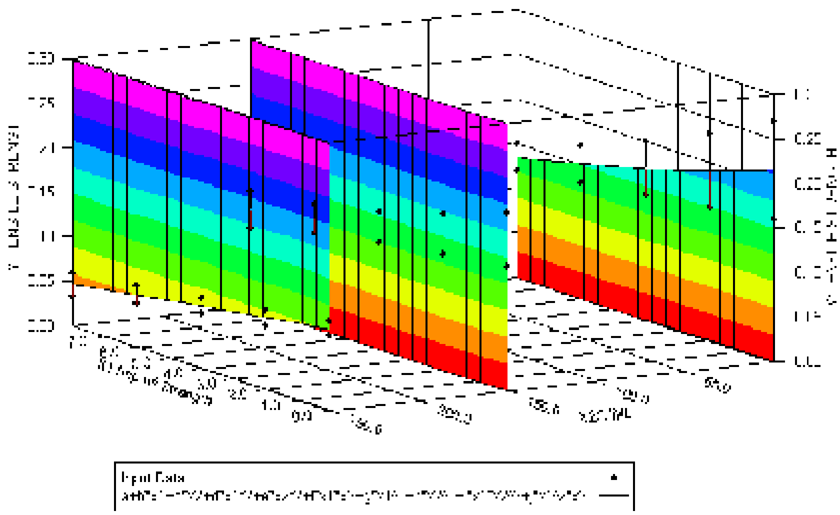

Figure (7) Indicates the model fitted data for impact strength property for both locally and international (RHDPE) due to best fit property tensile strength.

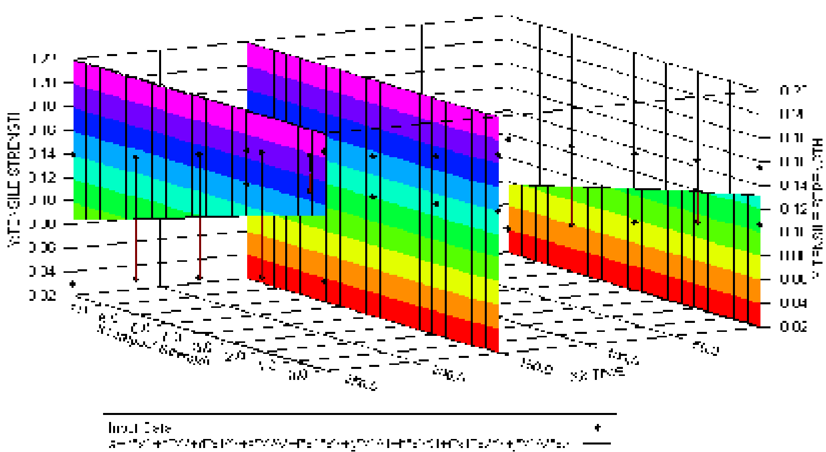

Figure (8) The fit model for Recycling LDPE for both sources locally and internationally at constant optimum temperature (50°C) with respect to base fitting tensile strength.

Thermo-mechanical /modulus of elasticity Property

The experimental data for both PE wastes (RHDPE and RLDPE) stated that an increasing of contaminates concentration was caused an increasing in values of above modulus property for different a range of aging exposure time (0, 150, 250) hrs, with a little deviation in values from both sources locally and internationally at higher value of weathering time 250 hr for RHDPE estimate normalized results and for RLDPE wastes respectively, as shown in Figures (9, 10). Also the experimental data shows high values of modulus for international RHDPE and locally RLDPE wastes.

Then an introducing of these data were achieved in order to optimize an suitable modeling software program function that would give a high quality best fitting results (correction factor, deviation, and coefficients), also to examine if the analyzed property was a basic one for others (Thermo-mechanical property), then a best fitting occurred for the applied data above as shown in Figures (11, 12). And Table (3) shows the results of this fitting.

Table (3) The coefficients of best fit model from both PE wastes HDPE AND LDPE.

Coefficient	Value	
	RHDPE	RLDPE
a	62.12	65.328
b	7.836	2.464
c	$-4.358*10^{11}$	$5*10^{11}$
d	0.396	0.734
e	$4.649*10^{9}$	$-5.335*10^{9}$
f	-0.012	$4.96*10^{-2}$
g	-1.753	$1.749*10^{-3}$
h	$-1.162*10^{7}$	$1.333*10^{7}$
i	$2.5*10^{-5}$	$-9.801*10^{-5}$
j	$-7.84*10^{-4}$	$-2.988*10^{-3}$
R^2	0.93164	0.98177
V (%)	93.164	98.177

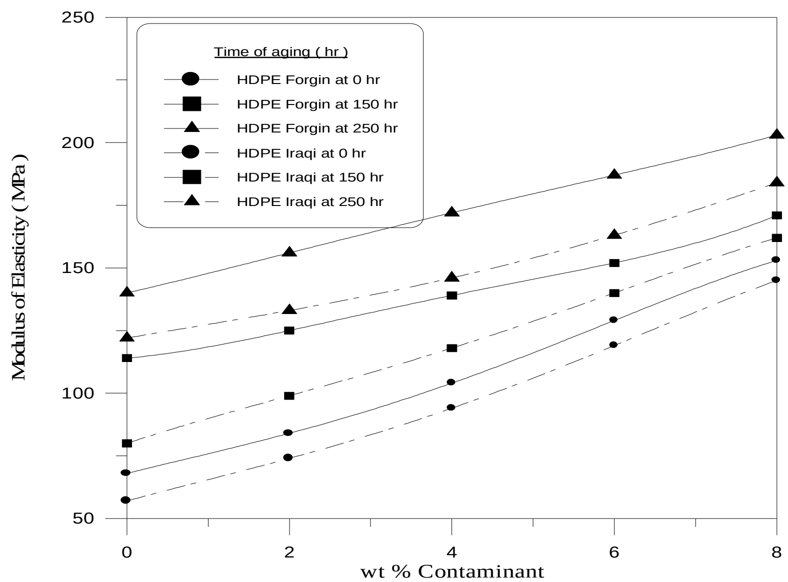

Figure (9) Indicates the experimental available data for modulus of elasticity for both locally and international RHDPE wastes.

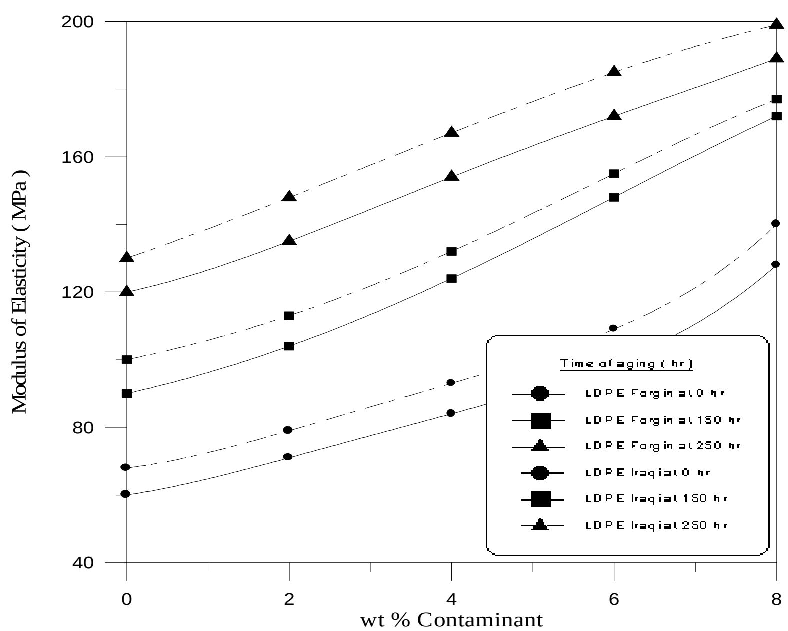

Figure (10) Shows the experimental data for modulus of elasticity for both source locally and international of RLDPE.

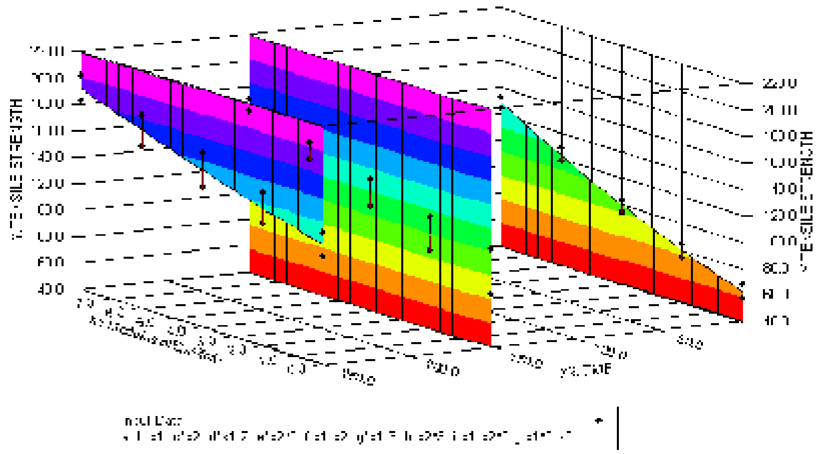

Figure (11) Indicates the model of data for modulus of elasticity property for both source locally and international wastes for (RHDPE) due to base tensile strength property.

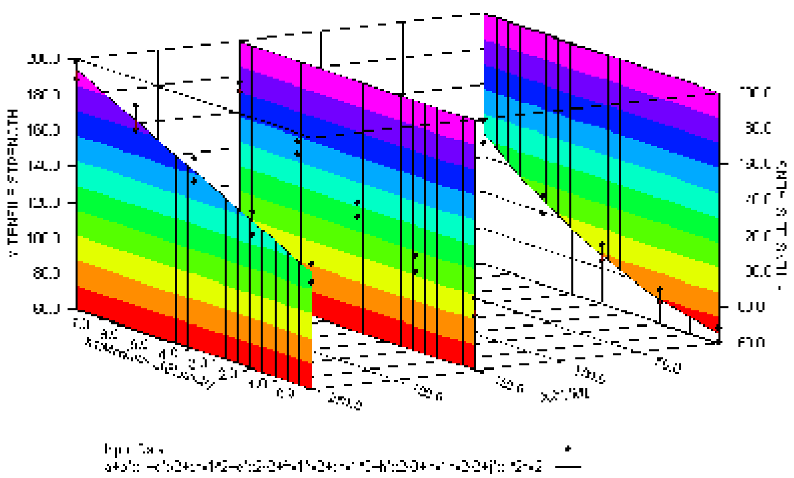

Figure (12) Indicates the results model for both source locally and international RLDPE for modulus property due to base tensile strength property.

Thermo-mechanical/ Elongation Property

The experimental data for PE wastes (RHDPE and RLDPE) showed that a decreasing in elongation at increasing both weathering variables (concentration of contaminates and time of aging) with preference for international RHDPE values and locally RLDPE wastes as shown in Figures (13, 14).

Afterward the application of different software model were achieved for both wastes (RHDPE and RLDPE) from both sources (locally and internationally), then the results was given an optimum high quality multi-polynomial model with preference for locally RLDPE of less residual and high correction factor quality (82%), as shown in Figures (15,16). The results of produced fitting model were shown in Table (4).

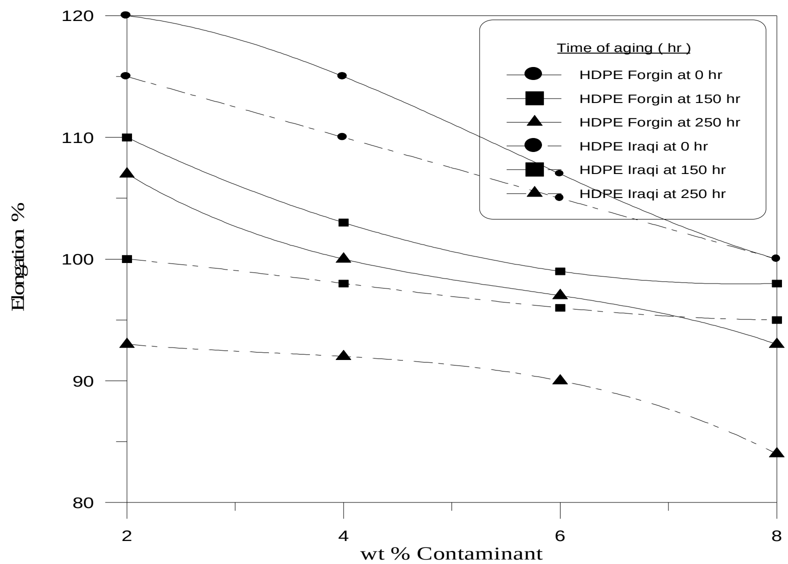

Figure (13) Indicates the experimental data for elongation for RHDPE.

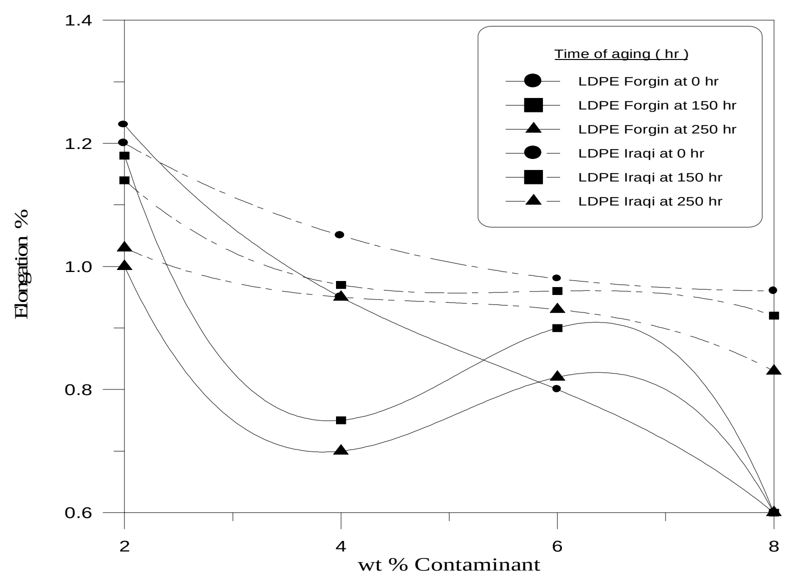

Figure (14) Indicates the experimental data for elongation for RLDPE.

Table (4) The coefficient of fitting model for both PE wastes types and sources for elongation property.

Coefficient	Value	
	RHDPE	RLDPE
a	-0.875	124.834
b	21.527	-3.744
c	$3.301*10^{11}$	$3.796*10^{10}$
d	-78.546	0.164
e	$-3.521*10^{9}$	$-4.049*10^{-8}$
f	$-5.918*10^{-3}$	$1.731*10^{-2}$
g	87.751	$-1.015*10^{-2}$
h	$8.803*10^{6}$	$1.012*10^{-6}$
i	$-7.081*10^{-6}$	$-5.749*10^{-5}$
j	$9.301*10^{-3}$	$1.463*10^{-4}$
R^2	0.67989	0.82523
V (%)	67.989	82.523

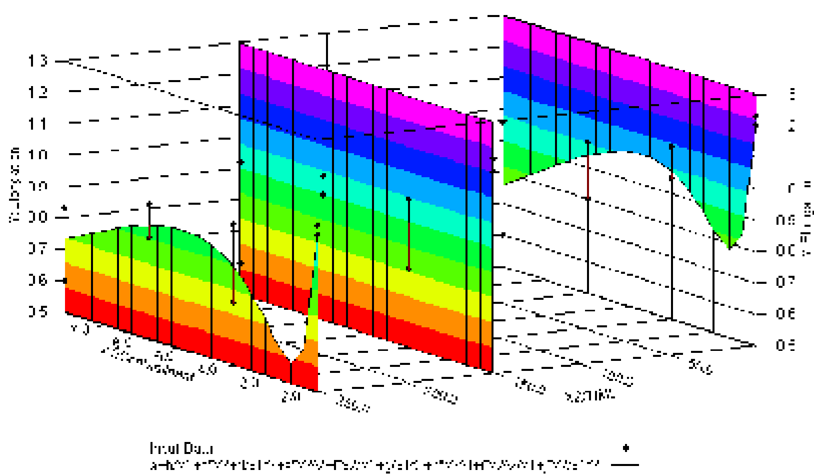

Figure (15) Model of data for RHDPE for both types of sources locally and international for elongation property.

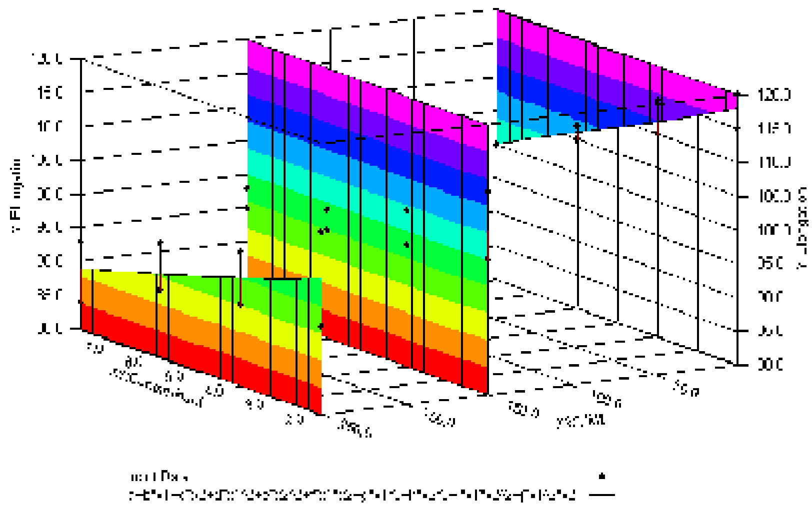

Figure (16) Shows the model structure for RLDPE from both sources locally and international wastes for elongation property.

Chemical Properties /Permeability / Length of Spectra Property

The experimental data for both PE wastes (RHDPE and RLDPE) from both sources (locally and internationally) were shown an increasing in permeability values with increasing both concentration of contaminants and temperature of exposure with high stability at 100% c at high length of spectra for locally and international (RLDPE) with preference of chemical properties for locally wastes (RHDPE and RLDPE), as shown in Figures (17, 18). Then applied the available experimental data in a different software programs and the results of this modeling was shown in Figures (19, 20). The result of this optimum fitting such as coefficients correction factor and deviation were shown in Table (5). The optimum multi-polynomial result model has high quality of fitting 96-97 % and similar residual functions and deviations (30, 34) for both wastes.

Table (5) Shows the Coefficients of fitting model for both types of PE(RHDPE) and (RLDPE) wastes.

Coefficient	Value	
	RHDPE	RLDPE
a	$-3.566*10^{7}$	$6.389*10^{12}$
b	$4.744*10^{9}$	$7.829*10^{6}$
c	$-1.421*10^{13}$	$-8.611*10^{8}$
d	$-8.328*10^{-7}$	$6.696*10^{-7}$
e	$6.720*10^{12}$	$-4.446*10^{9}$

f	**$-2.242*10^{9}$**	**$-2.348*10^{5}$**
g	**$7.857*10^{-12}$**	**$3.646*10^{-11}$**
h	**$-7.891*10^{11}$**	**$3.816*10^{7}$**
i	**$2.633*10^{8}$**	**156.589**
j	**$1.681*10^{-7}$**	**$-1.446*10^{-8}$**
R^2	**0.9797**	**0.9649**
V (%)	**97.97**	**96.49**

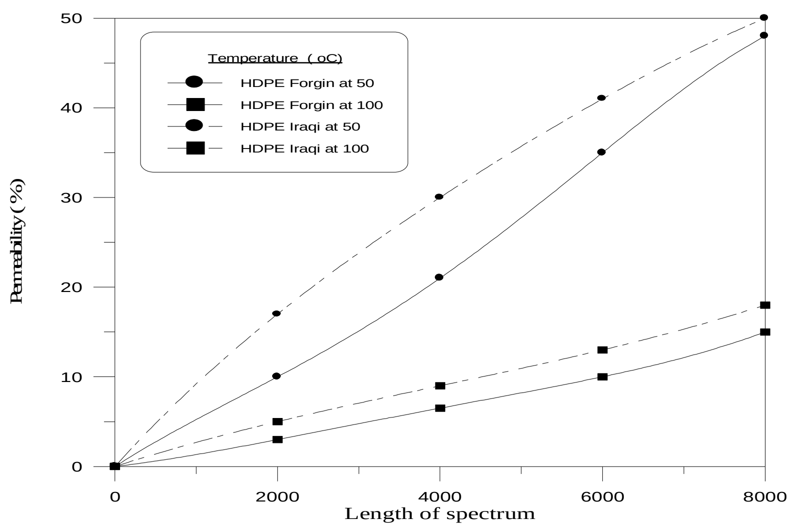

Figure (17) Shows the experimental results for permeability / Length of spectrum for RHDPE.

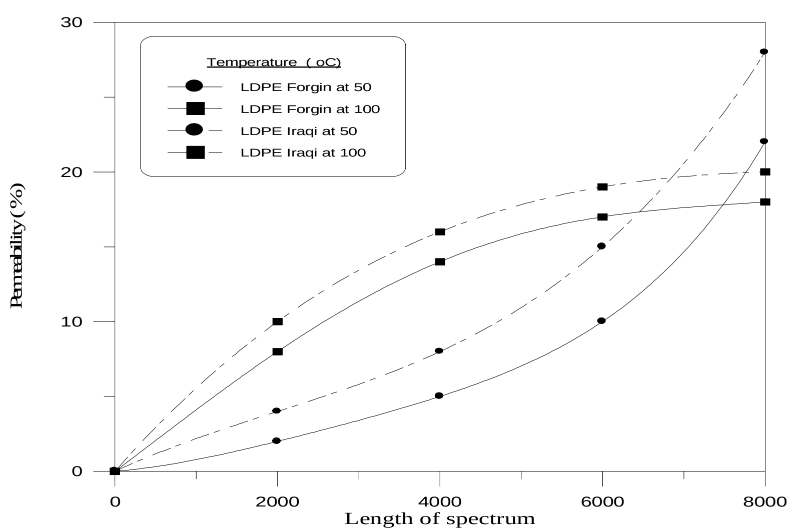

Figure (18) Shows the experimental results for permeability / Length of spectrum for RLDPE waste.

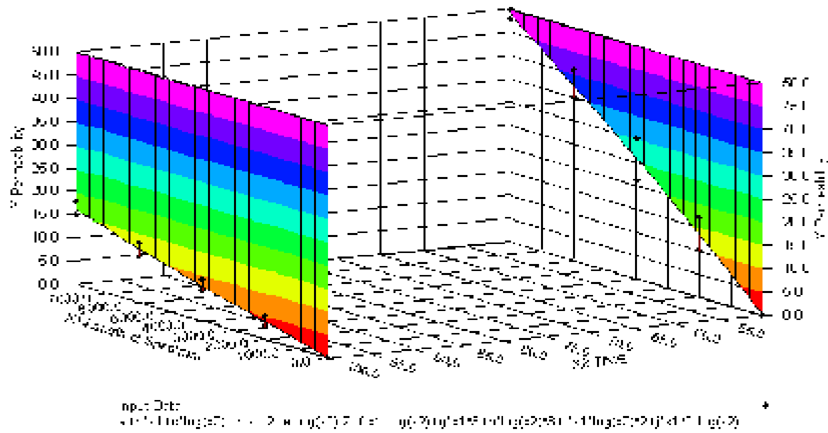

Figure (19) Models of data profile for Permeability / Length of spectrum for RHDPE.

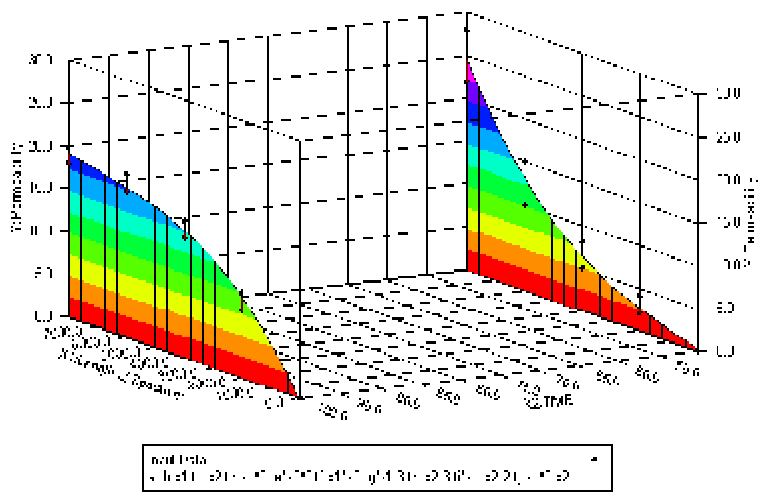

Figure (20) shows the model of data profile for Permeability / Length of spectrum property for RLDPE from both wastes locally and internationally.

Chemical properties/Permeability / Thickness Property

The experimental data for both wastes of PE (RHDPE and RLDPE) were shown a decreasing in permeability values with increasing both thickness of specimen and length of spectra for optimum samples from both type of wastes RHDPE and RLDPE with preference for short length of spectra at 400 A for both type of wastes, see Figures (21, 22).

The application of these optimum result data from both type of wastes on the different software modeling programs were shown different type of model system and number of coefficients as shown in equations and Tables (6), also the 3D histogram appearance of models were shown in figures (23, 24) [22,23].

$$Y_{RHDPEP} = a + \frac{b}{x_1} + \frac{c}{x_2} + \frac{d}{x_2^2} \qquad \dots (2)$$

$$Y_{RLDPEP} = a + b \log x_1 + \frac{c}{x_2} + \frac{d}{x_2^2} + \frac{e}{x_2^3} \qquad \dots (3)$$

Table (6) Shows the Coefficients of fitting model for both types of PE wastes.

Coefficient	Value	
	RHDPE	RLDPE
a	$-1.784*10^{16}$	$-3.401*10^{16}$
b	$1.943*10^{6}$	-83.049
c	$2.14*10^{19}$	$2.199*10^{19}$
d	$-5.711*10^{21}$	$1.17*10^{22}$
e		$-6.023*10^{24}$
R^2	0.9858	0.9604
V (%)	98.58	96.04

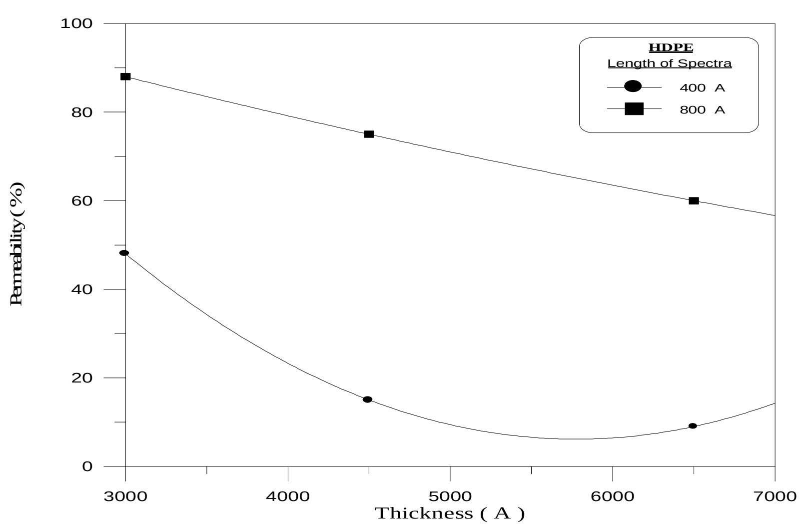

Figure (21) Shows the experimental data for permeability / thickness property for RHDPE waste.

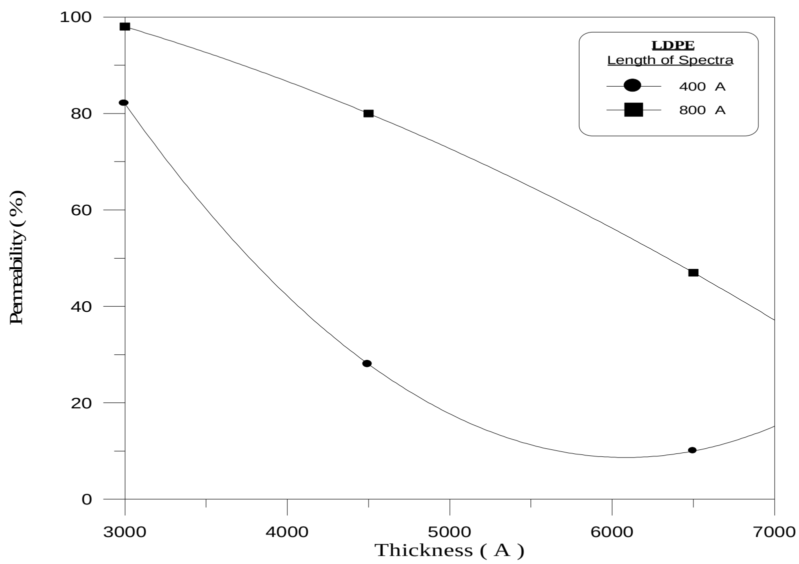

Figure (22) Shows the experimental data for permeability / thickness property for RLDPE waste.

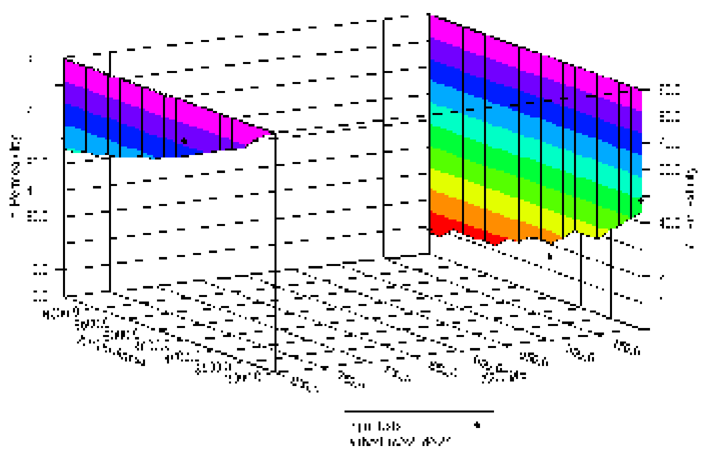

Figure (23) Shows the model of fitting data of Permeability / thickness property for RHDPE wastes.

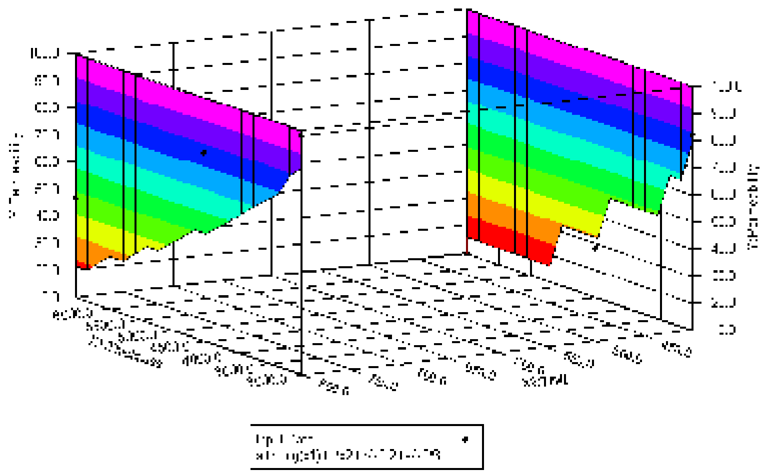

Figure (24) Shows the model of fitting data of Permeability / thickness property for RLDPE wastes.

CONCLUSIONS

From the above theoretical – software were model studied on the both types of PE wastes (RHDPE and RLDPE) and sources (locally and internationally), it could concluded that:

1- The Thermo-mechanical properties such as tensile strength, modulus elasticity were the basic specify properties.

2- The chemical properties of permeability / length and permeability / thickness were the basic specify properties too.

3- The optimum fitting models for all comparison properties Thermo-mechanical and chemical properties is a multi-polynomial model function except of permeability / thickness property of log-polynomial model, see equations (1, 2, 3).

4- The optimum fitting model was fitted all sorting and characterization properties except of permeability / thickness due to input other weathering variables for both sources (locally and internationally) wastes and both types (RHDPE and RLDPE), and this was an advanced studied now.

5- The optimum weathering variables for comparison was concentration of contaminates and time of aging, also the optimum basic property for comparison was tensile strength, modulus of elasticity and permeability.

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