Intrinsic viscosity [η], K_{wert}-Value and viscosity average molecular relationship for some polymers

T. Al-Ahmad and F. Al-Deri
Department of Chemistry, Faculty of Sciences, Damascus University, Syria

Received 17/02/2011
Accepted 22/08/2011

ABSTRACT

In this work, the dilute solution properties of poly (lactic acid) (PLA), polystyrene (PS), polycarbonate (PC) and polybutene-1 (PB-1) and a relationship between K_{wert}-Value and intrinsic viscosity [η] was obtained.

Relative viscosity (η_{rel}) for 0.1 and 0.4 (g/mol) solutions was experimentally determined using UBBELOHDE viscometer. The obtained values of relative viscosity were used to determined K_{wert}-Value, intrinsic viscosity and molecular weight for the studied polymers.

The results show that the relationship between K_{wert}-Value and intrinsic viscosity [η] does not depend on the polymer type and concentration.

Key words: Relative viscosity, Intrinsic viscosity, Viscosity average molecular weight relationship, K_{wert}-Value.

العلاقة بين اللزوجة المميزة [η]، K_{wert}-Value، ومعدل الوزن الجزيئي اللزوجي M_v لبولي حمض اللبن (PLA) والبولي ستيرين (PS) والبولي كربونات (PC) والبولي بوتين-1 (PB-1) في الحالة السائلة

ثورة الأحمد و فواز الديري

قسم الكيمياء ــ كلية العلوم ــ جامعة دمشق ــ سورية

تاريخ الإيداع 2011/02/17

قبل للنشر في 2011/08/22

الملخّص

نظراً إلى أهمية تعيين اللزوجة المميزة [η] في الحالة السائلة للبوليمرات ولاسيما المجالات التطبيقية كالسماكة والمتانة وسرعة التدفق، قمنا بتعيين اللزوجة المميزة [η] و K_{wert}-Value للبوليمرات المدروسة وذلك باستخدام جهاز UBBELOHDE وعلاقة فيكنشر Fikentsher. قمنا بحساب K_{wert}-value من علاقة فيكنشر بالاعتماد على قيم تجريبية للزوجة النسبية η_r ثم بطريقة كمبيوترية تزايداً وتناقصاً بمقدار 0.5 حتى 100 لـ K_{wert}-Value، عُيِّنت η_r و M_v المقابلة لـ K_{wert}-Value وللبوليمرات المدروسة جميعها.

إنّ العلاقة بين K_{wert}-Value واللزوجة المميزة تخضع لسلوكية قانون الاستطاعة Power Law ولا تعتمد هذه العلاقة، على التركيز ولا على نوع البوليمر. يمكن تعميم هذه الدراسة على العديد من البوليمرات مثل البولي بروبيلن PP والبولي إيتيلن PE والبولي أميد PA وبولي كلوريد الفينيل PVC، كما تسمح لنا الدراسة بتعيين الدليلين 'α، 'K في الصيغة $[\eta]= K'.[K_{wert}\text{-Value}]^{\alpha'}$ والممكن من خلالهما تشخيص البوليمرات لإيجاد علاقة بين [η] و K_{wert}-Value ومعدل الوزن الجزيئي اللزوجي.

الكلمات المفتاحية: اللزوجة النسبية، اللزوجة المميزة، علاقة معدل الوزن الجزيئي اللزوجي، K_{wert}-Value

INTRODUCTION

The measurement of the intrinsic viscosity for a dilute polymer solution is a particularly important method for determining molecular weight. Frequently this method is slow, and sometimes expensive. In order to handle large numbers of samples, especially on a routine basis, rapid, inexpensive methods are required. The molecular weight of polymer is a very important parameter for polymer processing especially in the molten state (extrusion and injection). The high molecular weight grades from the polymer (high viscosity) could be suitable for using in extrusion process, whereas the low molecular one is suitable for injection molding. All in all, it could be said that the determination of intrinsic viscosity gives direct idea about the suitable processing method [1].

The term "dilute" is usually applied to polymer solution containing no more than 1g of polymer per 100ml of solution [2]. At such concentration of low molecular weight-mass substances, the solute molecules in the solution practically do not interact with one another [3]. In polymer solution and owing to the very large size of macromolecules, a higher dilution is required for complete separation.

In studying dilute polymer solution, instead of the absolute value of the viscosity coefficient one often uses the so-called relative viscosity (viscosity ratio), which is the ratio of the solution viscosity to pure solvent:

$$h_{rel} = \frac{h_{solution}}{h_{solvent}} \qquad \textbf{(1)}$$

To determine the relative viscosity, the time of efflux of the solution and the solvent are measured by the same viscometer, taking the density of the dilute solution equal to that of the pure solvent $\rho=\rho_0$ then:

$$h_{rel} = \frac{t}{t_0} \qquad \textbf{(2)}$$

The efflux time of the solution t and solvent t_0 are determined at a strictly fixed temperature, because viscosity depends on temperature. It should be borne in mind that Poiseuilles law is valid only for luminary flow, which can be maintained by observing a definite relation between the viscosity of the liquid, the capillary radius and the rate of efflux.

The specific viscosity of a solution is the viscosity increase (due to the presence of polymer) divided by the viscosity of the pure solvent [4] [5]:

$$h_{sp} = \frac{h_{solution} - h_{solvent}}{h_{solvent}} \qquad \textbf{(3)}$$

The reduced viscosity is the ratio of specific viscosity to the concentration

$$h_{red} = \frac{h_{sp}}{C} \qquad \textbf{(4)}$$

For commercial purposes the molecular weight is usually characterised from measurement of the viscosity of dilute solution. It has been shown that, for dilute solution, the relation between viscosity and molecular weight (in this case, the viscosity average molecular weight may be given by the relationship of the Mark-Houwink [3]:

$$[h] = K.M^{a} \qquad \textbf{(5)}$$

Where: K and α are constant, K and α values for the studied polymers are listed in Table 1.

M - Is the molecular weight.

[η]- Is the intrinsic viscosity or limiting viscosity number.

Table 1. K and α for the studied polymers

Polymer	PS Chloroform, 25ºC[3]	PC Chloroform, 25ºC[3]	PLA Chloroform, 25ºC [4]	PB-1 Heptan 60 ºC[3]
K(100ml/g)	0.000123	0.000112	0.000221	0.00015
α	0.74	0.82	0.77	0.69

For example, it has been common in practice to characterize the molecular weight of a PVC polymer by its Fikentscher K_{wert}-Value [6] rather than to quote an actual figure for molecular weight. This is not the same K as given in the above equation but is obtained from the following relationship and is a measure of the molecular weight. The lower the K_{wert}-Value, the lower the molecular weight [7]:

$$Log\eta_{rel} = \left(\frac{75k^2}{1+1.5\times k\times C} + k \right) C \qquad (6)$$

Where: η_{rel} - relative viscosity

C- concentration (g/100ml)

K_{wert}-Value=1000×k

EXPERIMENTS

Material

Poly(lactic acid) (PLA) (ESUN™ A- 1001) [density =1.25g/cm^3) (21.5ºC), MFI=1.25 g/min (190ºC/2.18kg)] was supplied by Bright China Industrial Company. Ltd (Shenzhen, China), the selected grade is an extrusion material; it was dried at 70ºC for 6 hours before using. Polystyrene (PS) (SABIC®125PS) [density=1.05g/cm^3, MFI=7 g/10min (200°C/5Kg)] was supplied by Sabic (KSA). Polycarbonate (PC) (LEXAN OQ1026 Risen) (density = 1.2 g/cm^3, MFR = 11 cm^3/10min (250 °C/1.2 Kg)) was supplied by Sabic (KSA). Polybutene-1 (PB-1) (Ylem PB-1) was supplied by JUNGBO CO (Korea) [MFI= 0.4 g/10min (ASTM D 1238), density = 0.93 g/cm^3 (ASTM 1505)].

Apparatus and Experiment Condition.

Relative viscosity, specific viscosity and intrinsic viscosity of the studied polymers are measured in different solvents and at suitable temperature using UBBELOHDE viscometer. The time of efflux of the solution and the solvent are measured by the same viscometer. The concentration C is expressed in grams of solute per 100 milliliters of solution .The concentration C of studied polymers was 0.1and 0.4 (g/100ml).

Results and discussion:

Relative viscosity values of the studied polymers solution were determined using UBBELOHDE viscometer and by using equation (2). K_{wert}-Values were determined by using equation (6). Table 2 shows the measured values of η_{rel} and K_{wert}-Value.

Table 2. The values of η_{rel} and K_{wert} for studied polymer at 0.1 and 0.4 (g/mol)

Polymer	PS	PC	PLA	PB-1
$\eta_{rel(0.1)}$	1.1007	1.045	1.113	1.0938
$\eta_{rel(0.4)}$	1.454	1.190	1.521	1.419
K_{wert}- Value	68.5	44.5	73.0	66.0

[η] values of studied polymers were calculated from the η_{rel} values and by using equations (7),(8):

$$[h] = \frac{0.25(h_{rel} - 1) + (1.725 Log h_{rel})}{C} \quad \textbf{(7)}$$

$$[h] = \frac{\sqrt{2(h_{sp} - h_{rel})}}{C} \quad \textbf{(8)}$$

The obtained values from equations (7), (8) were similar and the viscosity average- molecular weight (M_v) of the studied polymer could be calculated by using Mrak-Houwink equation (5).

Then the calculated K_{wert}-Value was given new values from 1 to 100 (increasing and decreasing by a factor of 0.5) and the faced values of η_{rel}, [η] and M_v where calculated using the computer

Table 3. K_{wert}-Value, η_{rel}, [η] and M_v of the studied polymers (C = 0.1 g/100ml)

K_{wert}-value	η_{rel}	[η] (100ml/g)	M_v (PLA)	M_v (PS)	M_v (PC)	M_v (PB-1)
0.5	1.000119	0.001193	55925.5	192301.3	65779.42	348314.8
1	1.000248	0.002473	55934.8	192334.5	65789.7	348379.4
1.5	1.000384	0.003839	55944.73	192370.1	65800.67	348448.5
2	1.00053	0.005292	55955.3	192407.9	65812.33	348521.9
2.5	1.000684	0.00683	55966.48	192447.9	65824.69	348599.7
3	1.000846	0.008455	55978.3	192490.2	65837.74	348681.8
3.5	1.001018	0.010166	55990.75	192534.7	65851.49	348768.3
4	1.001198	0.011963	56003.83	192581.5	65865.93	348859.3
4.5	1.001387	0.013847	56017.54	192630.6	65881.07	348954.5
5	1.001584	0.015817	56031.88	192681.9	65896.91	349054.2
5.5	1.00179	0.017873	56046.85	192735.4	65913.44	349158.3
6	1.002005	0.020015	56062.45	192791.3	65930.67	349266.8
6.5	1.002228	0.022243	56078.68	192849.4	65948.59	349379.6
7	1.00246	0.024558	56095.54	192909.7	65967.22	349496.9
7.5	1.002701	0.026959	56113.04	192972.3	65986.54	349618.5
8	1.00295	0.029446	56131.17	193037.2	66006.56	349744.6
8.5	1.003208	0.032019	56149.93	193104.3	66027.27	349875

9	1.003475	0.034678	56169.33	193173.7	66048.69	350009.9
9.5	1.003751	0.037424	56189.36	193245.4	66070.81	350149.2
10	1.004035	0.040256	56210.02	193319.4	66093.63	350292.9
10.5	1.004328	0.043174	56231.32	193395.6	66117.14	350441
11	1.00463	0.046178	56253.26	193474.1	66141.36	350593.6
11.5	1.00494	0.049268	56275.83	193554.9	66166.29	350750.6
12	1.005259	0.052445	56299.04	193637.9	66191.91	350912
12.5	1.005587	0.055707	56322.89	193723.3	66218.24	351077.9
13	1.005924	0.059056	56347.38	193810.9	66245.27	351248.2
13.5	1.006269	0.062491	56372.5	193900.9	66273.01	351423
14	1.006623	0.066012	56398.27	193993.1	66301.45	351602.3
14.5	1.006986	0.06962	56424.67	194087.6	66330.6	351786
15	1.007358	0.073313	56451.72	194184.4	66360.46	351974.2
15.5	1.007738	0.077093	56479.41	194283.5	66391.02	352166.8
16	1.008127	0.080959	56507.74	194384.9	66422.3	352364
16.5	1.008525	0.084911	56536.72	194488.6	66454.28	352565.6
17	1.008932	0.08895	56566.34	194594.7	66486.97	352771.8
17.5	1.009348	0.093074	56596.6	194703	66520.37	352982.4
18	1.009772	0.097285	56627.52	194813.7	66554.49	353197.5
18.5	1.010206	0.101583	56659.07	194926.6	66589.32	353417.2
19	1.010648	0.105966	56691.28	195041.9	66624.86	353641.4
19.5	1.011099	0.110436	56724.14	195159.5	66661.12	353870.1
20	1.011559	0.114992	56757.64	195279.5	66698.09	354103.4
20.5	1.012027	0.119634	56791.8	195401.8	66735.78	354341.2
21	1.012505	0.124362	56826.61	195526.4	66774.19	354583.6
21.5	1.012991	0.129177	56862.07	195653.4	66813.32	354830.5
22	1.013487	0.134078	56898.19	195782.7	66853.17	355082
22.5	1.013991	0.139066	56934.96	195914.3	66893.74	355338.1
23	1.014504	0.14414	56972.38	196048.3	66935.03	355598.8
23.5	1.015026	0.1493	57010.47	196184.7	66977.04	355864.1
24	1.015557	0.154546	57049.21	196323.4	67019.78	356134
24.5	1.016098	0.159879	57088.61	196464.5	67063.25	356408.5
25	1.016647	0.165299	57128.68	196608	67107.44	356687.6
25.5	1.017205	0.170804	57169.4	196753.8	67152.36	356971.4
26	1.017772	0.176397	57210.79	196902.1	67198.01	357259.8
26.5	1.018348	0.182075	57252.85	197052.7	67244.4	357552.8
27	1.018933	0.18784	57295.56	197205.7	67291.51	357850.6
27.5	1.019527	0.193692	57338.95	197361	67339.36	358153
28	1.02013	0.19963	57383.01	197518.8	67387.94	358460.1
28.5	1.020742	0.205655	57427.73	197679	67437.26	358771.9
29	1.021363	0.211766	57473.13	197841.6	67487.31	359088.4

29.5	1.021993	0.217964	57519.19	198006.6	67538.11	359409.6
30	1.022633	0.224248	57565.94	198174.1	67589.65	359735.5
30.5	1.023281	0.230619	57613.35	198343.9	67641.92	360066.2
31	1.023939	0.237077	57661.45	198516.2	67694.95	360401.7
31.5	1.024606	0.243621	57710.22	198690.9	67748.71	360741.9
32	1.025282	0.250252	57759.67	198868.1	67803.23	361086.8
32.5	1.025967	0.25697	57809.81	199047.7	67858.49	361436.6
33	1.026661	0.263774	57860.62	199229.8	67914.5	361791.2
33.5	1.027365	0.270665	57912.13	199414.3	67971.26	362150.6
34	1.028078	0.277643	57964.31	199601.3	68028.78	362514.8
34.5	1.0288	0.284708	58017.19	199790.8	68087.05	362883.8
35	1.029531	0.29186	58070.75	199982.7	68146.08	363257.7
35.5	1.030272	0.299098	58125.01	200177.1	68205.86	363636.5
36	1.031022	0.306424	58179.96	200374	68266.41	364020.1
36.5	1.031781	0.313836	58235.6	200573.5	68327.71	364408.7
37	1.032549	0.321335	58291.94	200775.4	68389.78	364802.1
37.5	1.033327	0.328922	58348.98	200979.8	68452.62	365200.5
38	1.034114	0.336595	58406.72	201186.7	68516.22	365603.8
38.5	1.034911	0.344355	58465.15	201396.2	68580.59	366012
39	1.035717	0.352203	58524.3	201608.2	68645.74	366425.2
39.5	1.036533	0.360137	58584.15	201822.7	68711.65	366843.4
40	1.037357	0.368159	58644.7	202039.8	68778.34	367266.6
40.5	1.038192	0.376268	58705.97	202259.4	68845.81	367694.8
41	1.039036	0.384464	58767.94	202481.6	68914.06	368128
41.5	1.039889	0.392748	58830.63	202706.4	68983.08	368566.2
42	1.040752	0.401118	58894.03	202933.7	69052.89	369009.5
42.5	1.041624	0.409576	58958.15	203163.6	69123.49	369457.9
43	1.042506	0.418122	59022.99	203396.1	69194.87	369911.3
43.5	1.043398	0.426755	59088.56	203631.2	69267.04	370369.9
44	1.044299	0.435475	59154.84	203868.9	69340.01	370833.6
44.5 (PC)	1.04521	0.444283	59221.85	204109.2	69413.76	371302.4
45	1.04613	0.453178	59289.59	204352.1	69488.31	371776.3
45.5	1.04706	0.462161	59358.06	204597.7	69563.66	372255.5
46	1.048	0.471231	59427.26	204845.9	69639.81	372739.8
46.5	1.048949	0.480389	59497.19	205096.7	69716.76	373229.3
47	1.049909	0.489635	59567.86	205350.2	69794.52	373724.1
47.5	1.050878	0.498969	59639.27	205606.4	69873.09	374224.1
48	1.051856	0.50839	59711.42	205865.2	69952.46	374729.3
48.5	1.052845	0.517899	59784.31	206126.7	70032.65	375239.9
49	1.053843	0.527497	59857.95	206390.9	70113.65	375755.7
49.5	1.054852	0.537182	59932.34	206657.8	70195.46	376276.8

50	1.05587	0.546955	60007.48	206927.4	70278.1	376803.3
50.5	1.056898	0.556816	60083.37	207199.7	70361.56	377335.2
51	1.057936	0.566765	60160.02	207474.8	70445.84	377872.4
51.5	1.058984	0.576802	60237.42	207752.5	70530.95	378415
52	1.060042	0.586927	60315.59	208033	70616.89	378963
52.5	1.06111	0.597141	60394.52	208316.3	70703.66	379516.4
53	1.062188	0.607443	60474.21	208602.4	70791.26	380075.3
53.5	1.063276	0.617833	60554.67	208891.2	70879.7	380639.7
54	1.064374	0.628311	60635.91	209182.8	70968.99	381209.6
54.5	1.065482	0.638878	60717.91	209477.2	71059.11	381785
55	1.066601	0.649534	60800.7	209774.3	71150.08	382365.9
55.5	1.067729	0.660278	60884.26	210074.3	71241.9	382952.4
56	1.068868	0.67111	60968.6	210377.2	71334.57	383544.4
56.5	1.070017	0.682032	61053.73	210682.8	71428.1	384142.1
57	1.071176	0.693041	61139.65	210991.3	71522.48	384745.4
57.5	1.072346	0.70414	61226.35	211302.7	71617.72	385354.3
58	1.073526	0.715328	61313.85	211616.9	71713.83	385968.9
58.5	1.074716	0.726604	61402.15	211934	71810.8	386589.3
59	1.075916	0.737969	61491.24	212254	71908.63	387215.3
59.5	1.077127	0.749424	61581.14	212576.9	72007.34	387847
60	1.078349	0.760967	61671.84	212902.7	72106.93	388484.6
60.5	1.07958	0.7726	61763.34	213231.4	72207.39	389127.9
61	1.080823	0.784321	61855.66	213563.1	72308.74	389777
61.5	1.082076	0.796132	61948.8	213897.7	72410.97	390432
62	1.083339	0.808032	62042.75	214235.2	72514.08	391092.8
62.5	1.084613	0.820022	62137.52	214575.7	72618.09	391759.5
63	1.085897	0.832101	62233.11	214919.2	72722.99	392432.2
63.5	1.087193	0.84427	62329.53	215265.7	72828.79	393110.7
64	1.088499	0.856528	62426.78	215615.2	72935.48	393795.3
64.5	1.089815	0.868876	62524.86	215967.7	73043.08	394485.8
65	1.091143	0.881313	62623.78	216323.3	73151.59	395182.3
65.5	1.092481	0.89384	62723.54	216681.9	73261.01	395884.9
66 (PB-1)	1.09383	0.906457	62824.14	217043.5	73371.35	396593.5
66.5	1.09519	0.919164	62925.59	217408.2	73482.6	397308.3
67	1.09656	0.931961	63027.89	217776	73594.77	398029.1
67.5	1.097942	0.944849	63131.04	218146.9	73707.86	398756.1
68	1.099334	0.957826	63235.05	218520.8	73821.89	399489.3
68.5 (PS)	1.100738	0.970893	63339.92	218897.9	73936.84	400228.7
69	1.102153	0.984051	63445.65	219278.2	74052.73	400974.4
69.5	1.103578	0.997299	63552.25	219661.6	74169.56	401726.3
70	1.105015	1.010638	63659.72	220048.1	74287.33	402484.4

70.5	1.106463	1.024067	63768.07	220437.8	74406.05	403248.9
71	1.107922	1.037586	63877.3	220830.7	74525.72	404019.8
71.5	1.109392	1.051197	63987.4	221226.8	74646.34	404797
72	1.110873	1.064898	64098.39	221626.1	74767.92	405580.7
72.5	1.112366	1.07869	64210.28	222028.6	74890.46	406370.8
73 (PLA)	1.11387	1.092572	64323.05	222434.4	75013.97	407167.4
73.5	1.115386	1.106546	64436.73	222843.5	75138.45	407970.4
74	1.116912	1.120611	64551.3	223255.8	75263.9	408780
74.5	1.118451	1.134767	64666.78	223671.4	75390.33	409596.2
75	1.12	1.149014	64783.17	224090.3	75517.74	410419
75.5	1.121562	1.163353	64900.47	224512.5	75646.13	411248.3
76	1.123134	1.177783	65018.69	224938.1	75775.52	412084.4
76.5	1.124719	1.192305	65137.83	225367	75905.89	412927.1
77	1.126315	1.206918	65257.9	225799.3	76037.27	413776.6
77.5	1.127922	1.221623	65378.9	226234.9	76169.65	414632.9
78	1.129542	1.236419	65500.83	226673.9	76303.03	415495.9
78.5	1.131173	1.251308	65623.7	227116.4	76437.43	416365.7
79	1.132816	1.266288	65747.51	227562.3	76572.84	417242.5
79.5	1.134471	1.281361	65872.26	228011.6	76709.27	418126.1
80	1.136137	1.296525	65997.97	228464.4	76846.73	419016.6
80.5	1.137816	1.311782	66124.64	228920.7	76985.21	419914.1
81	1.139506	1.327131	66252.26	229380.4	77124.73	420818.7
81.5	1.141209	1.342573	66380.85	229843.7	77265.28	421730.2
82	1.142924	1.358107	66510.4	230310.5	77406.88	422648.9
82.5	1.14465	1.373734	66640.93	230780.8	77549.52	423574.6
83	1.146389	1.389453	66772.44	231254.7	77693.21	424507.5
83.5	1.14814	1.405265	66904.93	231732.2	77837.96	425447.6
84	1.149904	1.42117	67038.41	232213.3	77983.77	426394.9
84.5	1.151679	1.437169	67172.87	232697.9	78130.65	427349.4
85	1.153467	1.45326	67308.34	233186.3	78278.6	428311.3
85.5	1.155268	1.469444	67444.81	233678.2	78427.62	429280.4
86	1.15708	1.485722	67582.28	234173.9	78577.72	430257
86.5	1.158906	1.502094	67720.76	234673.2	78728.91	431241
87	1.160743	1.518558	67860.26	235176.2	78881.18	432232.4
87.5	1.162594	1.535117	68000.78	235683	79034.56	433231.4
88	1.164457	1.551769	68142.33	236193.5	79189.03	434237.8
88.5	1.166332	1.568515	68284.9	236707.7	79344.61	435251.9
89	1.168221	1.585355	68428.52	237225.7	79501.29	436273.5
89.5	1.170122	1.602289	68573.17	237747.6	79659.1	437302.8
90	1.172036	1.619318	68718.87	238273.2	79818.02	438339.8
90.5	1.173962	1.63644	68865.62	238802.7	79978.07	439384.6

91	1.175902	1.653657	69013.43	239336.1	80139.25	440437.1
91.5	1.177855	1.670969	69162.3	239873.3	80301.57	441497.5
92	1.17982	1.688375	69312.24	240414.4	80465.03	442565.7
92.5	1.181799	1.705876	69463.24	240959.5	80629.64	443641.8
93	1.183791	1.723472	69615.33	241508.5	80795.4	444725.9
93.5	1.185796	1.741163	69768.5	242061.4	80962.32	445818
94	1.187814	1.758949	69922.76	242618.3	81130.4	446918.2
94.5	1.189846	1.77683	70078.12	243179.3	81299.65	448026.4
95	1.191891	1.794807	70234.57	243744.2	81470.08	449142.8
95.5	1.193949	1.812879	70392.13	244313.2	81641.69	450267.3
96	1.196021	1.831047	70550.81	244886.3	81814.49	451400.1
96.5	1.198106	1.84931	70710.6	245463.4	81988.48	452541.2
97	1.200205	1.86767	70871.51	246044.7	82163.67	453690.5
97.5	1.202318	1.886125	71033.55	246630.1	82340.06	454848.3
98	1.204444	1.904676	71196.73	247219.6	82517.66	456014.5
98.5	1.206584	1.923324	71361.04	247813.4	82696.48	457189.1
99	1.208737	1.942068	71526.51	248411.3	82876.53	458372.2
99.5	1.210905	1.960909	71693.13	249013.4	83057.8	459563.9
100	1.213086	1.979846	71860.9	249619.8	83240.3	460764.3

Table 4. K_{wert}-Value, η_{rel}, [η] and M_v of the studied polymers (C = 0.4 g/100ml)

Kwer-value	η_{rel}	[η]	M_v (PLA)	M_v (PS)	M_v (PC)	M_v (PB-1)
0.5	1.000478	0.001194	55951.53	192394.4	65808.18	348495.7
1	1.000991	0.002473	55988.77	192527.6	65849.3	348754.6
1.5	1.001538	0.00384	56028.54	192669.9	65893.22	349031
2	1.00212	0.005292	56070.85	192821.3	65939.94	349325.1
2.5	1.002737	0.006831	56115.69	192981.8	65989.47	349637
3	1.003389	0.008456	56163.09	193151.4	66041.8	349966.5
3.5	1.004076	0.010167	56213.02	193330.1	66096.94	350313.8
4	1.004798	0.011964	56265.52	193518	66154.9	350678.8
4.5	1.005555	0.013847	56320.56	193715	66215.67	351061.7
5	1.006347	0.015817	56378.18	193921.2	66279.27	351462.5
5.5	1.007174	0.017872	56438.35	194136.5	66345.7	351881.2
6	1.008036	0.020013	56501.11	194361.2	66414.97	352317.8
6.5	1.008934	0.022241	56566.44	194595	66487.08	352772.5
7	1.009866	0.024554	56634.36	194838.1	66562.04	353245.2
7.5	1.010834	0.026954	56704.87	195090.6	66639.86	353736
8	1.011838	0.029439	56777.98	195352.3	66720.53	354245
8.5	1.012877	0.03201	56853.7	195623.4	66804.09	354772.2
9	1.013951	0.034667	56932.04	195903.9	66890.52	355317.8

9.5	1.015061	0.037411	57013	196193.8	66979.83	355881.7
10	1.016207	0.04024	57096.59	196493.1	67072.05	356464
10.5	1.017388	0.043155	57182.83	196801.9	67167.17	357064.9
11	1.018606	0.046155	57271.71	197120.2	67265.2	357684.3
11.5	1.019859	0.049242	57363.26	197448.1	67366.16	358322.4
12	1.021149	0.052415	57457.48	197785.6	67470.06	358979.3
12.5	1.022475	0.055674	57554.38	198132.7	67576.9	359654.9
13	1.023837	0.059018	57653.97	198489.4	67686.7	360349.5
13.5	1.025235	0.062449	57756.26	198855.9	67799.47	361063.1
14	1.02667	0.065965	57861.27	199232.1	67915.21	361795.7
14.5	1.028142	0.069568	57969.01	199618.1	68033.95	362547.6
15	1.02965	0.073256	58079.48	200014	68155.7	363318.7
15.5	1.031196	0.077031	58192.71	200419.7	68280.46	364109.2
16	1.032778	0.080891	58308.7	200835.4	68408.25	364919.2
16.5	1.034397	0.084838	58427.47	201261.1	68539.09	365748.8
17	1.036054	0.088871	58549.03	201696.9	68672.98	366598
17.5	1.037748	0.09299	58673.4	202142.7	68809.95	367467.1
18	1.03948	0.097195	58800.59	202598.6	68950	368356.2
18.5	1.041249	0.101486	58930.61	203064.8	69093.16	369265.2
19	1.043057	0.105863	59063.48	203541.3	69239.44	370194.5
19.5	1.044902	0.110327	59199.22	204028	69388.85	371144
20	1.046786	0.114877	59337.84	204525.2	69541.41	372114
20.5	1.048707	0.119514	59479.36	205032.8	69697.14	373104.5
21	1.050668	0.124237	59623.79	205550.8	69856.06	374115.7
21.5	1.052667	0.129046	59771.16	206079.5	70018.18	375147.8
22	1.054705	0.133942	59921.48	206618.8	70183.52	376200.8
22.5	1.056781	0.138925	60074.77	207168.8	70352.1	377274.9
23	1.058898	0.143994	60231.04	207729.6	70523.93	378370.2
23.5	1.061053	0.14915	60390.33	208301.3	70699.05	379487
24	1.063248	0.154392	60552.63	208883.8	70877.46	380625.4
24.5	1.065483	0.159722	60717.98	209477.4	71059.19	381785.4
25	1.067758	0.165138	60886.4	210082	71244.26	382967.4
25.5	1.070073	0.170642	61057.9	210697.8	71432.68	384171.4
26	1.072429	0.176232	61232.52	211324.8	71624.49	385397.6
26.5	1.074825	0.18191	61410.26	211963.1	71819.7	386646.2
27	1.077262	0.187675	61591.15	212612.9	72018.34	387917.4
27.5	1.07974	0.193527	61775.21	213274	72220.42	389211.3
28	1.082259	0.199466	61962.47	213946.8	72425.98	390528.2
28.5	1.08482	0.205493	62152.95	214631.2	72635.03	391868.1
29	1.087423	0.211608	62346.67	215327.3	72847.6	393231.4
29.5	1.090068	0.21781	62543.66	216035.3	73063.71	394618.2

30	1.092754	0.2241	62743.95	216755.2	73283.39	396028.6
30.5	1.095484	0.230478	62947.55	217487.1	73506.67	397463
31	1.098256	0.236944	63154.49	218231.2	73733.57	398921.4
31.5	1.101071	0.243498	63364.81	218987.4	73964.12	400404.2
32	1.103929	0.25014	63578.52	219756	74198.35	401911.5
32.5	1.106831	0.256871	63795.65	220537	74436.27	403443.6
33	1.109777	0.26369	64016.24	221330.5	74677.93	405000.6
33.5	1.112767	0.270597	64240.3	222136.7	74923.35	406582.9
34	1.115801	0.277593	64467.88	222955.6	75172.56	408190.5
34.5	1.11888	0.284678	64698.99	223787.3	75425.58	409823.8
35	1.122003	0.291852	64933.67	224632	75682.46	411483.1
35.5	1.125172	0.299115	65171.94	225489.8	75943.22	413168.5
36	1.128387	0.306467	65413.85	226360.8	76207.89	414880.2
36.5	1.131647	0.313908	65659.41	227245	76476.5	416618.7
37	1.134953	0.321439	65908.67	228142.7	76749.08	418384
37.5	1.138306	0.329059	66161.65	229054	77025.68	420176.5
38	1.141706	0.336769	66418.39	229979	77306.32	421996.4
38.5	1.145153	0.344569	66678.93	230917.7	77591.04	423844.1
39	1.148647	0.35246	66943.28	231870.4	77879.86	425719.7
39.5	1.152189	0.36044	67211.5	232837.2	78172.84	427623.7
40	1.15578	0.368511	67483.62	233818.2	78470	429556.1
40.5	1.159418	0.376672	67759.66	234813.5	78771.37	431517.4
41	1.163106	0.384924	68039.68	235823.2	79077.01	433507.9
41.5	1.166842	0.393267	68323.7	236847.7	79386.94	435527.8
42	1.170629	0.401701	68611.77	237886.8	79701.2	437577.5
42.5	1.174465	0.410226	68903.92	238940.9	80019.83	439657.2
43	1.178352	0.418843	69200.19	240010	80342.88	441767.4
43.5	1.182289	0.427551	69500.62	241094.4	80670.37	443908.2
44	1.186277	0.436351	69805.26	242194.1	81002.36	446080.1
44.5 (PC)	1.190317	0.445243	70114.13	243309.3	81338.89	448283.4
45	1.194408	0.454227	70427.3	244440.2	81679.99	450518.3
45.5	1.198552	0.463304	70744.79	245587	82025.71	452785.4
46	1.202749	0.472473	71066.66	246749.7	82376.1	455084.9
46.5	1.206999	0.481735	71392.94	247928.6	82731.19	457417.1
47	1.211302	0.49109	71723.68	249123.9	83091.04	459782.5
47.5	1.215659	0.500538	72058.92	250335.6	83455.68	462181.4
48	1.220071	0.51008	72398.72	251564.1	83825.17	464614.2
48.5	1.224537	0.519715	72743.12	252809.4	84199.55	467081.3
49	1.229059	0.529445	73092.16	254071.7	84578.88	469583
49.5	1.233637	0.539268	73445.9	255351.3	84963.19	472119.8
50	1.238271	0.549186	73804.38	256648.3	85352.55	474692.1

50.5	1.242961	0.559199	74167.66	257962.9	85746.99	477300.2
51	1.247709	0.569306	74535.78	259295.3	86146.57	479944.7
51.5	1.252514	0.579508	74908.8	260645.7	86551.35	482625.9
52	1.257377	0.589806	75286.77	262014.3	86961.37	485344.2
52.5	1.262299	0.6002	75669.74	263401.3	87376.68	488100.1
53	1.267281	0.610689	76057.76	264806.9	87797.36	490894
53.5	1.272322	0.621275	76450.9	266231.3	88223.44	493726.5
54	1.277423	0.631957	76849.21	267674.8	88654.98	496597.9
54.5	1.282584	0.642736	77252.74	269137.4	89092.05	499508.7
55	1.287807	0.653612	77661.55	270619.6	89534.69	502459.4
55.5	1.293092	0.664585	78075.7	272121.4	89982.97	505450.5
56	1.298439	0.675656	78495.25	273643.1	90436.95	508482.4
56.5	1.303849	0.686824	78920.26	275185	90896.69	511555.8
57	1.309323	0.698091	79350.79	276747.2	91362.24	514671
57.5	1.31486	0.709456	79786.91	278330.1	91833.68	517828.7
58	1.320463	0.72092	80228.68	279933.8	92311.06	521029.2
58.5	1.32613	0.732484	80676.15	281558.6	92794.45	524273.2
59	1.331863	0.744146	81129.41	283204.8	93283.92	527561.3
59.5	1.337663	0.755909	81588.51	284872.6	93779.52	530893.9
60	1.343529	0.767771	82053.51	286562.2	94281.33	534271.6
60.5	1.349463	0.779734	82524.5	288274	94789.42	537695
61	1.355466	0.791798	83001.54	290008.1	95303.85	541164.7
61.5	1.361537	0.803963	83484.69	291764.9	95824.7	544681.3
62	1.367678	0.81623	83974.04	293544.6	96352.04	548245.3
62.5	1.37389	0.828598	84469.65	295347.6	96885.93	551857.4
63	1.380172	0.841069	84971.6	297174	97426.46	555518.2
63.5	1.386525	0.853642	85479.96	299024.2	97973.69	559228.3
64	1.392951	0.866318	85994.81	300898.5	98527.71	562988.4
64.5	1.39945	0.879098	86516.23	302797.1	99088.59	566799.2
65	1.406023	0.891981	87044.29	304720.5	99656.41	570661.2
65.5	1.412669	0.904968	87579.08	306668.8	100231.2	574575.1
66 (PB-1)	1.419391	0.91806	88120.68	308642.3	100813.2	578541.7
66.5	1.426189	0.931257	88669.16	310641.5	101402.3	582561.7
67	1.433064	0.94456	89224.62	312666.7	101998.7	586635.6
67.5	1.440015	0.957968	89787.13	314718	102602.4	590764.4
68	1.447045	0.971482	90356.79	316796	103213.5	594948.6
68.5 (PS)	1.454154	0.985103	90933.68	318900.9	103832.2	599189.1
69	1.461342	0.998831	91517.89	321033	104458.5	603486.6
69.5	1.468611	1.012667	92109.52	323192.8	105092.5	607841.8
70	1.475961	1.026611	92708.65	325380.5	105734.2	612255.6
70.5	1.483393	1.040663	93315.37	327596.6	106383.9	616728.7

71	1.490908	1.054824	93929.78	329841.3	107041.5	621261.9
71.5	1.498507	1.069095	94551.99	332115.1	107707.2	625856.2
72	1.50619	1.083475	95182.08	334418.3	108381	630512.2
72.5	1.513959	1.097966	95820.15	336751.4	109063.2	635230.8
73 (PLA)	1.521814	1.112568	96466.31	339114.6	109753.6	640013
73.5	1.529756	1.127281	97120.65	341508.5	110452.6	644859.5
74	1.537787	1.142106	97783.29	343933.3	111160.1	649771.4
74.5	1.545906	1.157043	98454.33	346389.6	111876.2	654749.4
75	1.554115	1.172094	99133.87	348877.7	112601.2	659794.5
75.5	1.562416	1.187257	99822.02	351398	113335	664907.6
76	1.570808	1.202535	100518.9	353951	114077.8	670089.8
76.5	1.579293	1.217928	101224.6	356537.1	114829.7	675341.9
77	1.587871	1.233436	101939.3	359156.7	115590.9	680664.9
77.5	1.596545	1.249059	102663	361810.4	116361.3	686059.9
78	1.605314	1.264798	103395.9	364498.5	117141.2	691527.9
78.5	1.61418	1.280655	104138.2	367221.5	117930.6	697069.9
79	1.623144	1.296629	104889.8	369979.9	118729.8	702686.9
79.5	1.632206	1.312721	105651	372774.1	119538.7	708380
80	1.641369	1.328932	106421.9	375604.7	120357.5	714150.3
80.5	1.650632	1.345262	107202.6	378472.2	121186.4	719999
81	1.659997	1.361712	107993.2	381377	122025.5	725927.1
81.5	1.669466	1.378282	108793.8	384319.6	122874.8	731935.7
82	1.679039	1.394974	109604.7	387300.6	123734.6	738026.2
82.5	1.688717	1.411788	110425.9	390320.5	124604.9	744199.5
83	1.698502	1.428724	111257.6	393379.8	125486	750457
83.5	1.708395	1.445783	112099.9	396479.1	126377.8	756799.8
84	1.718396	1.462966	112952.9	399619	127280.7	763229.3
84.5	1.728507	1.480274	113816.8	402799.9	128194.6	769746.6
85	1.73873	1.497707	114691.8	406022.5	129119.8	776353.1
85.5	1.749065	1.515267	115577.9	409287.3	130056.4	783050
86	1.759514	1.532953	116475.5	412594.9	131004.5	789838.7
86.5	1.770078	1.550766	117384.5	415946	131964.3	796720.6
87	1.780758	1.568708	118305.1	419341.1	132936	803697
87.5	1.791556	1.586779	119237.6	422780.8	133919.7	810769.3
88	1.802473	1.604979	120182	426265.8	134915.5	817939
88.5	1.81351	1.62331	121138.6	429796.8	135923.6	825207.5
89	1.824668	1.641773	122107.5	433374.3	136944.2	832576.2
89.5	1.835949	1.660367	123088.8	436999	137977.4	840046.7
90	1.847355	1.679095	124082.8	440671.6	139023.5	847620.6
90.5	1.858886	1.697956	125089.7	444392.8	140082.5	855299.2
91	1.870544	1.716952	126109.5	448163.3	141154.6	863084.3

91.5	1.882331	1.736084	127142.5	451983.8	142240.1	870977.5
92	1.894248	1.755351	128188.8	455854.9	143339	878980.2
92.5	1.906296	1.774756	129248.7	459777.5	144451.6	887094.4
93	1.918478	1.7943	130322.3	463752.2	145578.1	895321.5
93.5	1.930794	1.813982	131409.9	467779.9	146718.6	903663.3
94	1.943246	1.833804	132511.6	471861.2	147873.3	912121.7
94.5	1.955835	1.853767	133627.6	475997	149042.5	920698.3
95	1.968564	1.873872	134758.1	480188	150226.2	929395
95.5	1.981433	1.89412	135903.3	484435.1	151424.7	938213.6
96	1.994445	1.914511	137063.5	488739	152638.3	947155.9
96.5	2.007601	1.935047	138238.8	493100.6	153867	956224
97	2.020903	1.955729	139429.5	497520.8	155111.2	965419.7
97.5	2.034352	1.976557	140635.8	502000.3	156371	974745
98	2.04795	1.997534	141857.9	506540.2	157646.6	984202
98.5	2.061699	2.018659	143095.9	511141.1	158938.2	993792.6
99	2.075601	2.039934	144350.3	515804.2	160246.2	1003519
99.5	2.089657	2.06136	145621.1	520530.2	161570.6	1013383
100	2.10387	2.082938	146908.7	525320.1	162911.7	1023387

**The highlighted rows are for the measured values*

Figures 1and 2 show the plot of [η] versus K_{wert}-Value for the studied PS and PC respectively. It is clearly seen that the relationship between [η] and K_{wert}-Value obeys the power law:

$$[h] = 0.0013K_{wert}^{1.562} \quad \text{(C=0.1 g/100ml)} \quad \mathbf{(9)}$$

$$[h] = 0.0012K_{wert}^{1.572} \quad \text{(C=0.4 g/100ml)} \quad \mathbf{(10)}$$

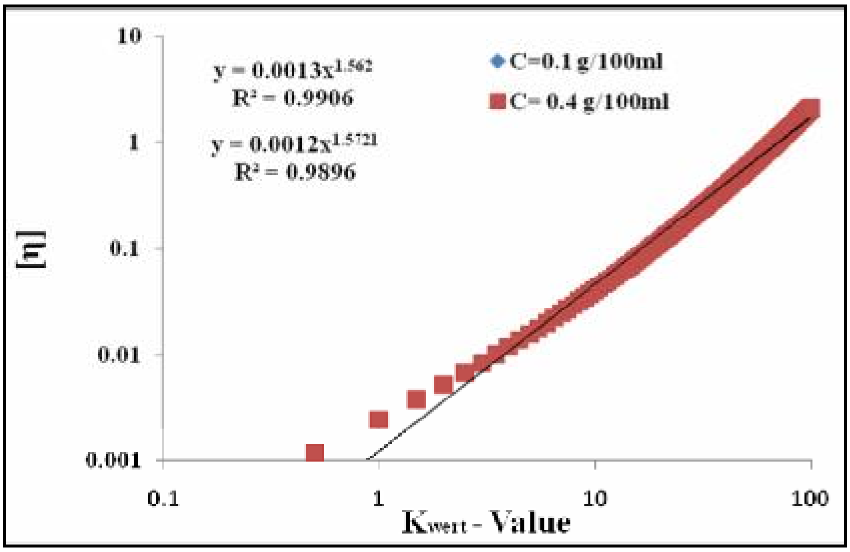

Fig. 1. [η] versus K_{wert}-Value of PS

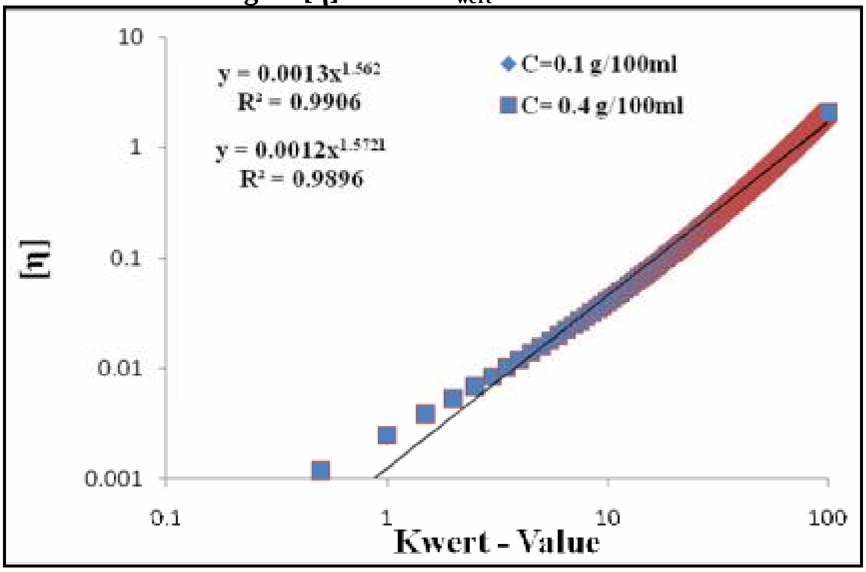

Fig. 2. [η] versus K_{wert}-Value of PC

It is clearly seen from Figures 1 and 2 that the relationship between intrinsic viscosity and K_{wert} – Value does not depend on the polymer type and concentration, where it was the same power equation for all studied polymers.

Equations (9) and (10) are similar to that of Mrak-Houwink, and could be used to calculate K_{wert}-Value. However, the constant of this equation (K', α') are not for a particular polymer-solvent pair as in of Mrak-Houwink equation (5). Tables 3 and 4 could be used to direct determination of the intrinsic viscosity, K_{wert}-Value and molecular weight for the studied polymers just by measuring the relative viscosity to the polymer solution in suitable solvent and temperature, and this table could be communalized to be used for all traditional polymers such as PP, PE, PA, PVC… where it could be index tables.

Conclusion

In this work the solution properties of polymer materials were studied, two solutions (0.1, 0.4 g/100ml) of PLA, PB-1, PS and PC were prepared, the relative viscosity of the prepared polymers was determined using UBBELOHDE viscometer so that intrinsic viscosity, Kwert-Value and molecular weight of the studied polymers were calculated. The following conclusions can be drawn from the results of the present work:

- The relationship between intrinsic viscosity and Kwert-Value obeys the power law.
- This relationship does not depend on the concentration, polymer and the temperature.
- Also it could be used to calculate K_{wert} -Value by using K' and α'.
- The tables in this work could be used as reference tables to determine the K_{wert}–Value, which related to suitable processing method for the polymer, directly from a single test for the polymer solution in the suitable solvent.

Acknowledgement

The authors are grateful to Mr. Honny Yoo (JUNGBO CO - Korea) for his aid in supplying PB-1, and gratefully thank Mrs. Ida Lau (Bright China Industrial Company. Ltd) for her aid in supplying PLA.

REFERENCES المراجع

1. **Ebewele RO. (2000). Polymer science and technology. CRC Press LLC Publication, Florida**
2. **Crawford RJ. (1998). Plastic engineering, Third Edition. Elsevier, London**
3. **Teraoka I. (2002). Polymer solution. Wiley inter science, New York**
4. **Ebewele RO. (2000). Polymer science and technology. CRC Press LLC Publication, Florida**
5. **Zeng JB, Li YD, Zhu QY, Yang KK, Wang XL, Wang YZ. (2009). A novel biodegradable multiblock poly (ester urethane) containing poly (l-lactic acid) and poly (butylene succinate) blocks. Polymer 50:1178–1186**
6. **Miles DC, Briston JH. (1968). Polymers technology. George Newnes Ltd. London**
7. **Bower, D. (2002). An introduction to polymer physics, Cambridge press, Cambridge**
8. **Sperling, LH. (2006). Introduction to physical polymer science. Wiley inter science, New York**