A Mathematic Modelling of The Dynamic Viscosity in Relation With The Shear Rate and Temperature For The Copolymer Hydrogenated Poly(Isoprene-Co-Styrene) Solutions

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Abstract: In this paper I undertook to determine the rheological characteristics of the copolymer hydrogenated poly(isoprene-co-styrene) solutions. I have studied the 3, 6, 10, and 12% concentrated solutions for a temperature interval from 40°C and 90°C in 10 degree steps, and for the shear rate from 3 to 1312 s^{-1} in the second domain. The measurements were performed using a Haake VT 550 rotational rheometer with a HV_1 sensor. The rheology of the solutions has been impacted by the shear rate, the temperature and the concentration of the copolymer hydrogenated poly(isoprene-co-styrene). I have found two models that successfully describe the rheological behaviour of the solutions compared to other models that do not consider the copolymer's concentration.

Keywords: dynamic; viscosity; shear rate; copolymer

1. Introduction

Viscosity is the most important physical feature of the lubricants for it varies with the temperature and the shear rate and determines their performance.

Multi-grade oils contain organic polymer additives to improve the viscosity index. The organic polymers are base oil soluble, have molar mass from 10^4 to 10^6 g/mol and are able to reduce the dynamic viscosity's dependence on the temperature [1-3].

The viscosity index additives are those polymers whose chains may be blocked by twisting them either in between or with the oil's, which alters the speed, the geometry and the molecular movement of the both components and varies along with the temperature [4-6]. The chains get blocked by twisting and therefore cannot move easily at high temperature as compared to no twisting and thus we have a loss in viscosity [7].

The performance of a polymer used as a viscosity index additive are being influenced by the structure, the concentration, the chemical stability, the oxidation thermal resistance, and the shearing stability or strength. For any given polymer, the shearing stability and the effect of viscosity increase or oil thickening varies inversely with the molar mass, while the shearing stability decreases with the increase in the latest, and the higher the mass the higher the viscosity [8]. When choosing a polymer to use as oil viscosity additive, one must keep a balance between its efficiency as a viscosity booster and its shearing stability [9].

The behaviour of an oil film between two surfaces that travel with respect to each other is quantified by the dynamic viscosity, a measure that correlates the shearing tension to the shear rate [10-12]. To determine the actual efficiency of a given polymer as a viscosity booster, one must know the rheological behaviour of its solutions over the widest range of shear rates.

While the rheological behaviour of certain viscosity boosters has been studied for low and high shear rates (10^4 - 10^6 s^{-1}), it has not been considered for intermediate shear rates. Usually, diluted solutions display a Newtonian behaviour while those semidiluted and concentrated behave like non-Newtonian fluids [13].

As the modification of the temperature-induced viscosity variation has a significant impact on the bearings' load capacity and the oil flowing rate, in many applications we need to know the viscosity-temperature relations [14].

Concerning the relation between the liquid lubricants' viscosity and temperature, there is a set of equations, some empirical, some theoretical. A first equation for the oils'

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viscosity-temperature of dependence was presented by Vogel for the viscosity temperature variation at zero shear rate, η_o (mPa.s) (1) [15]:

$$\eta_0 = k\ exp\left(\frac{\theta_1}{\theta_2 + t}\right) \qquad (1)$$

where T is the temperature in ^oC, and k (mPa.s), θ_1 (^oC) and θ_2 (^oC) are constants for a given oil.

The dynamic viscosity of the polymer solutions at high temperature of creases with the temperature according to the Andrade equation (2) [16]:

$$\eta = A \cdot 10^{B/T} \qquad (2)$$

where *A* and *B* are polymer constant characteristics.

Another equation that advances a dynamic viscosity's dependence on the temperature is (3) [17]:

$$\eta = A\ (t_c / S)^{t_c / B} \qquad (3)$$

where *A*, *B* and *S* are constants, and t_c – temperature in ^oC.

The non-Newtonian fluids' viscosity depends not only on the temperature but on the shear rate they are subjected to. The dependence of the dynamic viscosity on the shear rate is given by the Cross equation (4) [18]:

$$\frac{\eta_o - \eta}{\eta - \eta_\infty} = (K\dot{\gamma})^m \qquad (4)$$

where η is the lubricant's dynamic viscosity in mPa.s, η_∞ – the minimum dynamic viscosity achieved under the shear rate in mPa.s, K – a constant with time units, and *m* – the shear index, non-dimensional [19]. The degree of viscosity reduction or oil thinning under the shearing is given by the value of m: when it comes closer to zero, the fluid is Newtonian [20-23].

Most liquids that reduce their viscosity under the shearing action – behaving in a pseudo-plastic manner – display m values close to one.

The viscosity temperature variation for a zero shear rate is given by the equation (4), while we assume that the formula is the same for the η_∞ temperature of dependence. Thus the ratio r of the two viscosities [24]:

$$\eta_\infty / \eta_o = r \qquad (5)$$

r is a temperature-independent constant whose value is lubricant specific. Because it is difficult to obtain a η_∞ value, it is considered identical to the base oil's [25].

In this paper I undertook to determine the rheological characteristics of the copolymer hydrogenated poly(isoprene-co-styrene). I have studied the 3, 6, 10, and 12% concentrated solutions for a temperature interval from 40°C and 90°C in 10 degree steps, and for the shear rate from 3 to 1312 s^{-1} in the second domain. The measurements were performed using a Haake VT 550 rotational rheometer with a HV_1 sensor. The rheology of the solutions has been impacted by the shear rate, the temperature and the concentration of the copolymer hydrogenated poly(isoprene-co-styrene). I have found two models that successfully describe the rheological behaviour of the solutions compared to other models that do not consider the copolymer's concentration.

2. Materials

The chemical and physical properties of copolymer hydrogenated poly(isoprene-co-styrene) are: physical state – solid, form – white solid blocks, colour – compressed crumbs, odourless, flashpoint > 150^{o}C, water insoluble, not a hygroscopic matter, stable, density (15^{o}C) – 0.272 g.cm^{-3} and no hazardous decomposition.

The SAE 10W oil's physical and chemical properties are: form – homogeneous, yellowish brown liquid, specific odour, density (15^{o}C) – 0.875-0.910 kg·m^{-3}, kinematic viscosity at 40^{o}C - 90 cSt, kinematic viscosity at 100^{o}C - 8 cSt, dynamic viscosity (20ºC) - 65 cP, viscosity index – 70-100, solubility in organic solvents, petroleum, fat, water-insoluble, flash point > 200ºC, melting point - (-10) ÷ (-15)ºC, amount of coke – 0.03 – 0.5%. The utilized SAE 10W oil is mostly paraffinal and contains 75% saturated hydrocarbons.

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The of 3, 6, 10 and 12% copolymer hydrogenated poly(isoprene-co-styrene) solutions concentrations have been prepared at the room temperature through continuous mixing for several weeks.

A Haake VT 550 rotational drum viscosity meter has been used to determine the rheological features of the copolymer hydrogenated poly(isoprene-co-styrene) solutions concentrated. The rheological behaviour of the copolymer hydrogenated poly(isoprene-co-styrene) solutions in the SAE 10W oil has been studies on a Haake VT 550 viscosity meter with a HV_1 sensor that provides for shear rates from 3 to 1312 s^{-1} for a temperature range from 40 to 90°C.

3. Results and discussion

The of 3, 6, 10 and 12% copolymer hydrogenated poly(isoprene-co-styrene) solutions concentrations have been studied for temperatures from 40°C to 90°C, shear rates from 3 s^{-1} to 1312 s^{-1} and the second domain.

The Figure 1 shows variation dynamic viscosity with temperature of 3% copolymer hydrogenated poly(isoprene-co-styrene) solution concentration for the 437.9 s^{-1}, 729 s^{-1} and 1312 s^{-1} shear rates. The solution was studied in the 40-90^{o}C temperature range for the 145.8 s^{-1}, 243 s^{-1}, 437.9 s^{-1}, 729 s^{-1} and 1312 s^{-1} shear rates. As one can see from the curves, the solution's dynamic viscosity decreases with the increase of the temperature and the shear rate.

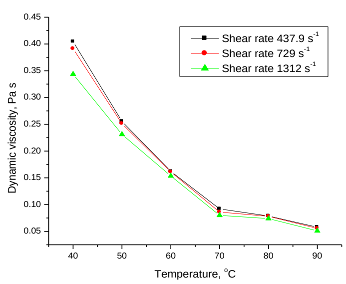

Fig. 1. Dynamic viscosity temperature variation for a 3% copolymer hydrogenated poly (isoprene-co-styrene) solution concentration for certain shear rates

For a 40°C temperature and a 145.8 s^{-1} shear rate, the 3% copolymer hydrogenated poly (isoprene-co-styrene) solution displays a dynamic viscosity of 0.4278 Pa s. If we increase the shear rate to 243 s^{-1} and keep the temperature constant, the solution's viscosity goes down to 0.4083 Pa.s. When keeping the shear rate constant at 243 s^{-1} and increasing the temperature of the copolymer hydrogenated poly(isoprene-co-styrene) solution, the dynamic viscosity reaches 0.2566 Pa s.

For a shear rate of 437.9 s^{-1} and a temperature range of 40 - 90°C, the dynamic viscosity of the copolymer hydrogenated poly(isoprene-co-styrene) solution is 0.4044 Pa.s for a temperature of 40°C and goes down to 0.0577 Pa. s at 90°C.

For a shear rate of 729 s^{-1} and a temperature range of 40 - 90°C, the dynamic viscosity of the solution reaches 0.3912 Pa.s at 40°C and decreases to 0.0555 Pa.s at 90°C.

For a shear rate of 1312 s^{-1} and a temperature range of 40 - 90°C, the dynamic viscosity of the copolymer hydrogenated poly(isoprene-co-styrene) solution is 0.3436 Pa.s at 40°C and goes by a polynomial curve down to 0.05083 Pa.s at 90°C. As one can see, at the temperatures of 80°C and 90°C the solution's dynamic viscosity displays a insignificant reduction even if we increase the shear rate.

The Table 1 shoes the shear rates for which we determined the dynamic viscosities of the 3% copolymer hydrogenated poly(isoprene-co-styrene) solution in relation with the temperature, the parameters A, B and C obtained by the polynomial fitting of the curve, the correlation coefficients obtained by the polynomial fitting, and the statistically obtained correlation coefficients.

The equation that describes the dynamic viscosity temperature of dependence for all of the solutions studied is (6):

$$\eta = A + Bt + Ct^2 \qquad (6)$$

where η – the solution's dynamic viscosity (Pa.s), t – temperature in ^{o}C, A, B, C – parameters that depend on the polymer's and solvent's nature, and R^2 – correlation coefficient.

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Table 1. The shear rate and the parameters A, B and C of described by the equation (6), and the correlation coefficients obtained by the polynomial fitting and statistically

Shear rate, s^{-1}	*A*	*B*	*C*	Correlation coefficients, R^2 equation (6)	Statistical correlation coefficients, R^2
437.9	1.2829	-0.0289	1.7149E-4	0.9955	0.8724
729	1.2360	-0.0277	1.6359E-4	0.9949	0.8763
1312	1.0441	-0.0228	1.3105E-4	0.9944	0.8949

For the 3% copolymer hydrogenated poly(isoprene-co-styrene) solution, the value of parameter A decreases from 1.2829 to 1.0441 for shear rates between 437.9 s^{-1} and 1312 s^{-1}. The parameter B displays very narrow values over the shear rate range in which we studied the solution. The parameter C goes down with the increase in the shear rate and the working temperature. The correlation coefficients determined by the equation (6) are close to one, which shows that the equation accurately describes the rheological behaviour of the solution.

The statistically determined correlation coefficients show every point's deviation from the straight line. As expected, the statistical correlation coefficients are much lower as the solution's dynamic viscosity exponentially decreases with the increase in the solution's temperature.

The Figure 2 shows the dynamic viscosity dependence on the shear rate for the 3% copolymer hydrogenated poly(isoprene-co-styrene) solution over the temperature range 40 - 90^{o}C.

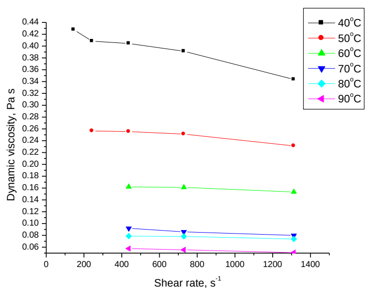

Fig. 2. Variation of the dynamic viscosity with the shear rate for a 3% copolymer hydrogenated poly(isoprene-co-styrene) solution for various temperatures

The rheogram of the 3% copolymer hydrogenated poly(isoprene-co-styrene) solution has been studied for several shear rates: 145.8 s^{-1}, 243 s^{-1}, 437.4 s^{-1}, 729 s^{-1} and 1312 s^{-1}, in the second domain. As one can see from the graph, for the temperatures of 60^{o}C, 70^{o}C, 80^{o}C and 90^{o}C, we only found three values for the dynamic viscosity and the slopes of the straight lines are pretty close to each other.

The equation that describes the rheological dependence of the dynamic viscosity on the shear rate for all of the copolymer hydrogenated poly(isoprene-co-styrene) solution is (7):

$$\eta = A + B\dot{\gamma} \tag{7}$$

where η - dynamic viscosity (Pa.s), *A*, *B* – parameters that depend on the polymer's and solvent's type, and $d\gamma/dt$ – shear rate (s^{-1}).

The Table 2 shows the temperatures of our 3% copolymer hydrogenated poly(isoprene-co-styrene) solution, the parameters A and B obtained by polynomial fitting, and the statistical correlation coefficients for the same straight lines.

The parameter A decreases with the increase in the temperature and reaches 0.0612 at 90^{o}C. The parameter B, which is the slope of the line, has close values at 60^{o}C, 70^{o}C, 80°C and 90°C. The correlation coefficients in the equation (7) display values close to one for all of the obtained lines. The statistical correlation coefficient has been determined for 40^{o}C only. I could not determine this correlation coefficient for the other lines as I had at least four determinations. 90^{o}C, the shear rates of 48.6 s^{-1} and 1312 s^{-1} and the second domain.

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Table 2. Temperature and parameters A and B of the equation (7), correlation coefficients obtained by polynomial fitting and the statistical correlation coefficients

Temperature, ^{0}C	*A*	*B*	Correlation coefficients, R^2 equation (7)	Statistical correlation coefficients, R^2
40	0.4330	-6.6178E-5	-0.9820	0.9643
50	0.2653	-2.4576E-5	-0.9683	-
60	0.1673	-1.0290E-5	-0.9743	-
70	0.0970	-1.3353E-5	-0.9829	-
80	0.0817	-5.8238E-6	-0.9728	-
90	0.0612	-7.8772E-6	-0.9999	-

The Figure 3 shows the dynamic viscosity variation with the temperature for a 6% copolymer hydrogenated poly(isoprene-co-styrene) solution for the shear rates of 145.8 s^{-1}, 243 s^{-1}, 437.4 s^{-1}, 729 s^{-1} and 1312 s^{-1}. The 6% solution has been studied over the temperature range of 40-90^{o}C, the shear rates of 48.6 s^{-1} and 1312 s^{-1} and the second domain.

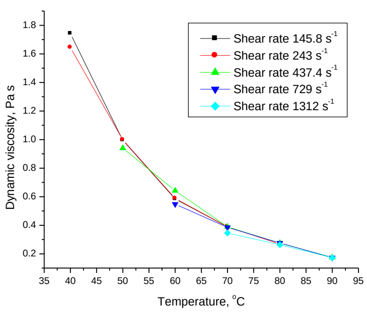

Fig. 3. Dynamic viscosity variation with the temperature for a 6% copolymer hydrogenated poly(isoprene-co-styrene) solution for various shear rates

For a temperature of 40°C and a shear rate of 48.6 s^{-1}, the 6% copolymer hydrogenated poly(isoprene-co-styrene) solution displays a dynamic viscosity of 1.6566 Pa s. If we increase the shear rate to 81 s^{-1} but keep the temperature constant at 40^{o}C, the dynamic viscosity reaches 1.68 Pa.s. When keeping the shear rate constant at 81 s^{-1} and increasing the solution's temperature by 10°C, the solution's dynamic viscosity goes down to 1.05 Pa.s.

The Table 3 shows the shear rates for which I have been able to depict the dynamic viscosity dependence on temperature, the parameters A, B and C obtained by polynomial fitting using the equation (6) and the statistical correlation coefficients.

The Table 3 shows that the parameter A goes down with the increase in the shear rate and in the temperature. The parameter B goes down with the increase in the shear rate of the 6% copolymer hydrogenated poly(isoprene-co-styrene) solution, while the parameter C is positive over the shear range of 145.8 s^{-1} and 729 s^{-1}. The parameter C displays a negative value for our solution at a shear rate of 1312 s^{-1}. The correlation coefficients are close to one over the shear rate range of 145.8 s^{-1} and 729 s^{-1}. Value 1 of the correlation coefficient is achieved for a shear rate of 1312 s^{-1}.

The Figure 4 shows the dynamic viscosity variation with the shear rate for a 6% copolymer hydrogenated poly(isoprene-co-styrene) solution over the temperature range of 40-90^{o}C and shear rates from 48.6 s^{-1} to 1312 s^{-1}.

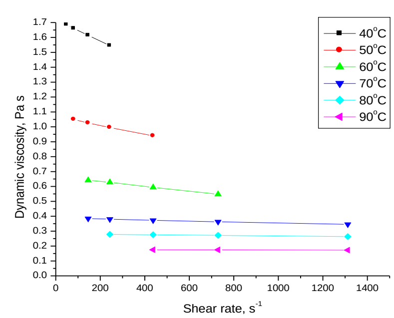

Fig. 4. Dynamic viscosity variation with the shear rate for a 6% copolymer hydrogenated poly(isoprene-co-styrene) solution at various temperatures

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Table 3. The shear rate, the parameters A, B and C in the equation (6), the correlation coefficients obtained by polynomial fitting, and the statistical correlation coefficients

Shear rate, s^{-1}	*A*	*B*	*C*	Correlation coefficients, R^2 equation (6)	Statistical correlation coefficients, R^2
145.8	7.3907	-0.1966	0.0014	0.9994	-
243	5.8612	-0.1418	9.0171E-4	0.9978	0.9065
437.4	3.6086	-0.0725	3.8229E-4	0.9979	0.9442
729	2.1042	-0.0350	1.5150E-4	0.9985	-
1312	0.6768	-0.0017	-4.3500E-5	1.0000	-

Table 4. Temperature, parameters A and B described by the equation (7), correlation coefficients obtained by polynomial fitting, and the statistical correlation coefficients.

Temperature, ^{0}C	*A*	*B*	Correlation coefficients, R^2 equation (7)	Statistical correlation coefficients, R^2
40	1.7202	-7.2274E-4	-0.9998	-
50	1.0722	-3.0576E-4	-0.9988	-
60	0.6663	-1.6231E-4	-0.9997	-
70	0.3884	-3.3113E-5	-0.9978	0.9956
80	0.2819	-1.3914E-5	-0.9995	-
90	0.1762	-2.5481E-6	-0.9978	-

As shown in the Figure 4, the slope is steeper at 40°C. The slopes of the closest lines correspond to the temperatures of 70°C, 80°C and 90°C. The Table 4 shows the temperatures for which we studied the solution, the parameters A and B obtained by the polynomial fitting of the obtained lines, the correlation coefficients obtained through the equation (7) and the statistical correlation coefficients.

Only for 70°C have we determined a statistical correlation coefficient which is close to one. We have not been able to determine that coefficient for other temperatures as we could not determine at least four values for the dynamic viscosity.

As one can see in the Table 4, the parameter A decreases with the temperature for the 6% copolymer hydrogenated poly(isoprene-co-styrene) solution, the parameter B which stands for the slope reaches a peak at 40°C while the slopes values are low for the temperatures between 70 and 90^{o}C. The correlation coefficients determined by the equation (7) are close to one for all the temperatures of the solution. The statistical coefficients could not be determined for all the temperatures of the solution because we only had a few values for the dynamic viscosities for certain temperatures. The Figure 5 shows the dynamic viscosity variation with the temperature for the 10% copolymer hydrogenated poly(isoprene-co-styrene) solution, for the shear rates of 16.2 s^{-1}, 27 s^{-1}, 48.6 s^{-1}, 81 s^{-1} and the second domain. The concentrated solution of copolymer hydrogenated poly(isoprene-co-styrene) has been studied over the temperature range of 40-90^{o}C and the whole range of the rheometer's shear rates.

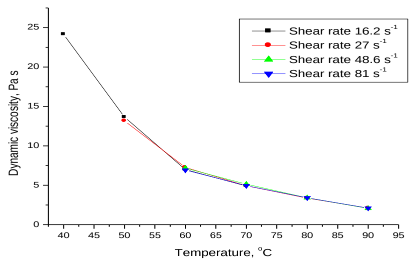

Fig. 5. Dynamic viscosity variation with the temperature of the 10% copolymer hydrogenated poly(isoprene-co-styrene) solution at various shear rates

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At a shear rate of 3 s^{-1} and a temperature of 40°C, the solution displays a dynamic viscosity of 22.8 Pa s. When increasing the shear rate to 5.4 s^{-1} and keeping the temperature constant, the dynamic viscosity slightly increases to 23.1 Pa.s. Keeping the shear rate constant at 5.4 s^{-1} and increasing the temperature by 10°C, the dynamic viscosity goes down to 14.175 Pa.s. For a shear rate of 9 s^{-1} and a temperature of 40°C, the dynamic viscosity reaches 25.2 Pa.s. When increasing the temperature by 10 or 20 °C and keeping the shear rate constant, the dynamic viscosity decreases and reaches 13.419 Pa.s and 5.67 Pa.s. At a shear rate of 145.8 s^{-1} and a temperature of 80°C, the dynamic viscosity reaches 3.2472 Pa s. For a temperature of 90°C and shear rates of 145.8 s^{-1} and 243 s^{-1}, the dynamic viscosity reaches 2.1 Pa.s and 2.0766 Pa.s.

The Table 5 shows the shear rates for which we could represent the dynamic viscosity versus the temperature, the parameters A, B and C obtained by the polynomial fitting of the curves, the correlation coefficients from the equation (6) and the statistical correlation coefficients.

The parameter A goes down with the increase in the shear rate from 108.7450 to 25.6095. The parameter B increases with the increase in the shear rate for the 10% copolymer hydrogenated poly(isoprene-co-styrene) solution. The parameter C goes down with the increase in the shear rate. The parameters A, B and C depend on both the type of the polymer and the solvent, and the temperature range of the solution. The correlation coefficients obtained from the equation (6) are close to one, which shows that the dynamic viscosity dependence on the temperature displays a polynomial reduction. The correlation coefficient has only been determined for a shear rate of 27 s^{-1}. As for the other values of the shear rate, we did not have enough values for the dynamic viscosity to determine the statistical correlation coefficients. The Figure 6 shows the dynamic viscosity variation with the shear rate for the copolymer hydrogenated poly(isoprene-co-styrene) solution over the entire temperature range.

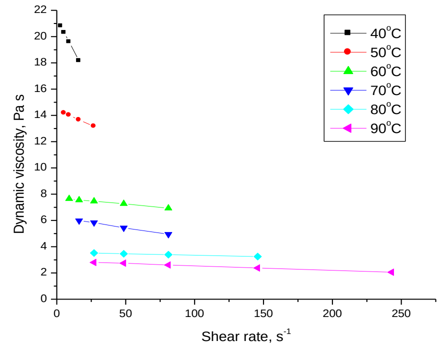

Fig. 6. Dynamic viscosity variation with the shear rate for a 10% copolymer hydrogenated poly(isoprene-co-styrene) solution at various temperatures

As one can see from the figure 6, the line displays the steepest slope at 40°C. The slopes for 80 and 90°C are very close.

The Table 6 shows the temperature range of the solution, the parameters A and B obtained by the polynomial fitting of the lines, the correlation coefficients obtained from the equation (7) and the statistical correlation coefficients.

As one can see in the Table 6, the parameter A goes down with the increase in the temperature and the shear rates. The parameter B increases with the increase in the temperature for the 10% copolymer hydrogenated poly(isoprene-co-styrene) solution. The parameter B stands for the slope, and these slopes are very close to each other for the temperatures of 80 and 90°C. The correlation coefficients obtained from the equation (7) are close to one, which indicates that this equation accurately describes the behaviour of the solution under study. The statistical correlation coefficients have been determined for 60 to 90°C only, and are close to one. For the other temperatures, we could not determine the correlation coefficients as we obtained few values for the dynamic viscosity of the solution. The Figure 7 shows the dynamic viscosity variation with the temperature for the 12% copolymer hydrogenated poly(isoprene-co-styrene) solution, for the temperatures of 70, 80 and 90°C only.

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Table 5. Shear rate, parameters A, B and C from the equation (6), correlation coefficients obtained by polynomial fitting, and the statistical correlation coefficients

Shear rate, s^{-1}	*A*	*B*	*C*	Correlation coefficients, R^2 equation (6)	Statistical correlation coefficients, R^2
16.2	108.7450	-2.9540	0.0210	0.9999	-
27	58.0926	-1.2642	0.0072	0.9850	0.8906
48.6	26.8639	-0.4331	0.0018	0.9999	-
81	25.6095	-0.4123	0.0017	0.9998	-

Table 6. Temperature, parameters A and B from the equation (7), correlation coefficients obtained by polynomial fitting, and statistical correlation coefficients

Temperature, ^{0}C	*A*	*B*	Correlation coefficients, R^2 equation (7)	Statistical correlation coefficients, R^2
40	21.3920	-0.2002	-0.9999	-
50	14.4302	-0.0470	-0.9996	-
60	7.7286	-0.0098	-0.9985	0.9970
70	6.2473	-0.0162	-0.9988	-
80	3.5766	-0.0023	-0.9992	-
90	2.8982	-0.0035	-0.9993	0.9986

The 12% copolymer hydrogenated poly(isoprene-co-styrene) solution has been studied at temperatures of 70, 80 and 90°C, shear rates of 9 s^{-1}, 16.2 s^{-1}, 27 s^{-1}, 48.6 s^{-1} and 81 s^{-1} in the second domain. That very viscous solution could not be studied for the 40-60^{o}C temperature range.

At 70°C for a shear rate of 9 s^{-1}, the solution displays the highest dynamic viscosity, 9.135 Pa.s. If we increase the temperature by 10°C and keep the shear rate constant at 9 s^{-1}, the dynamic viscosity goes down to 6.3 Pa s.

For an increase in the shear rate to 16.2 s^{-1}, at 70^{o}C the 12% copolymer hydrogenated poly(isoprene-co-styrene) solution reaches dynamic viscosity of 9.975 Pa s.

At a shear rate of 81 s^{-1} and a temperature of 80°C, the solution displays a dynamic viscosity of 6.23 Pa s. When increasing the solution's temperature by 10°C and keeping the shear rate at 81 s^{-1}, the dynamic viscosity reaches 4.48 Pa s.

The Table 7 shows the shear rates for which we could represent the Figure 7, the parameters A, B and C obtained by the polynomial fitting of the curves shown in the Figure 7, the correlation coefficients derived from the equation (6) and the statistical correlation coefficients.

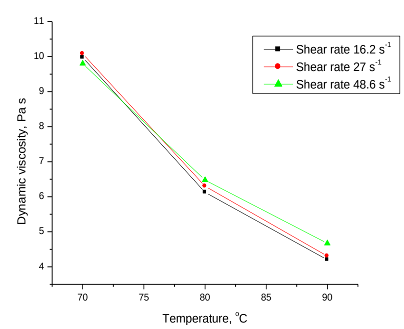

Fig. 7. Dynamic viscosity variation with the temperature for a 12% copolymer hydrogenated poly(isoprene-co-styrene) solution at various shear rates

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Table 7. The shear rate, the parameters A, B and C derived from the equation (6), the correlation coefficients obtained by polynomial fitting and the statistical correlation coefficients

Shear rate, s^{-1}	*A*	*B*	*C*	Correlation coefficients, R^2 equation (6)	Statistical correlation coefficients, R^2
16.2	90.8250	-1.8288	0.0097	1.0000	-
27	86.5200	-1.7168	0.0089	1.0000	-
48.6	75.6350	-1.4725	0.0076	1.0000	-

Table 8. Temperature, parameters A and B from the equation (7), correlation coefficients obtained by polynomial fitting and statistical correlation coefficients

Temperature, ^0C	*A*	*B*	Correlation coefficients, R^2 equation (7)	Statistical correlation coefficients, R^2
70	11.0711	-0.0405	-0.9966	-
80	6.4405	-0.0056	-0.9370	0.8780
90	4.7151	-0.0071	-0.9505	-

As shown in the Table 7, the parameter A goes down with the increase in the shear rate for our solution, the parameter B increases with the increase in the shear rate, while the parameter C goes down with the increase in the shear rate. All the correlation coefficients derived from the equation (6) are 1. For all the shear rates, the correlation coefficients could not be determined statistically because we only read 3 values for the dynamic viscosity.

The Figure 8 displays the dynamic viscosity variation with the shear rate for a 12% copolymer hydrogenated poly(isoprene-co-styrene) solution, over a temperature range of 70-90^{o}C and shear rates of 9-81 s^{-1}, the second domain.

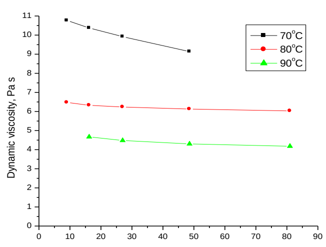

Fig. 8. Dynamic viscosity variation with the shear rate for a 12% copolymer hydrogenated poly(isoprene-co-styrene) solution at various temperatures

As one can see from the graph, the steepest slope of the solution occurs at 70°C, while the slopes for 80 and 90°C are close.

The Table 8 shows the temperature for which we studied the solution, the parameters A and B obtained by the polynomial fitting of the lines, the correlation coefficients derived from the equation (7) and the statistical correlation coefficients.

As shown in the Table 8, the parameter A goes down with the increase in the temperature and the shear rate while the parameter B which stands for the slope has similar values for 80 and 90°C. The correlation coefficients derived from the equation (7) are close to one and the statistical correlation coefficients could not be determined for all the temperatures but for 80° C. The obtained statistical correlation coefficient has a value well under one.

4. Conclusion

In this paper, I have studied the rheological behaviour of a copolymer hydrogenated poly(isoprene-co-styrene) solution of various concentrations for certain shear rates and temperatures. The reduction in the dynamic viscosity has been more visible at lower shear rates than at higher rates. The dynamic viscosity increases with the increase in the temperature

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and the increase in the concentration of the copolymer hydrogenated poly(isoprene-co-styrene) solution. Nevertheless, the results show that the viscosity of the copolymer solution has been more sensitive to higher temperatures. The equations (6) and (7) provide a good correlation between the dynamic viscosity and the shear rate, the concentration and the temperature. The computed parameters can be used to describe the rheology of the solution in accordance with the shear rate, concentration and temperature.

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