

## Mathematical Dependence of the Dynamic Viscosity in Relation with the Shear Rate for the of Copolymer Hydrogenated Poly(isoprene-co-styrene) Concentrated Solutions

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**Abstract:** In this paper I undertook to determine the rheological characteristics of copolymer hydrogenated poly (isoprene-co-styrene) solutions concentrated. The solutions studied were the concentrations 3, 6, 10 and 12 %. Rheology solutions are affected by concentration, temperature, shear rate and shear stress. The empirical relationship found, the dependence of the logarithm dynamic viscosity in relation with the logarithm shear rate accurately describe the rheological behavior of the solutions studied in comparison with other models in the literature include the concentration of the solution.

**Keywords:** solution concentrated; copolymer; relationship

### 1. Introduction

Viscosity of the polymer depends on the shear rate or velocity gradient applied, so they behave as non-Newtonian fluids. Studies conducted by many researchers on the dynamic behavior of macromolecules are based on the representation of a chain which rotates freely in a simple shear [1-4].

Under the action of shear stress and stretch macromolecules with the major axis oriented in the direction of flow [5, 7]. The degree of orientation depends on the ratio between the intensity of Brownian motion and the speed gradient size applies: the higher the velocity gradient is even smaller effect Brownian motion, thus increasing the effect of orientation, which leads to decrease viscosity [6-12].

The shear rate depends on the molar mass, concentration, temperature and nature of the polymer.

Non-Newtonian behavior of the polymer solution to flow is connected to the second stationary structural characteristics: the shape and size of the macromolecules asymmetric flow [13-17].

Due to the great length of the macromolecule in its size cross chain is oriented in stationary flow.

Shear stress applied concentrated polymer solutions will cause the destruction of certain structures present in solution and the orientation

of macromolecules and the elements resulting from the dissolution of associations [18-20].

In literature there are many empirical relationships describing the dependence of viscosity solutions of temperature, shear rate and shear stress and very little dependence describing logarithm of dynamic viscosity logarithm of shear rate [21-25].

This article proposes an empirical relationship of dependence logarithm dynamic viscosity in relation with logarithm shear rate. This relationship has the form:

$$\log \eta = \log \eta_0 + b \log \dot{\gamma} + c \log \dot{\gamma}^2 \quad (1)$$

where  $\log \eta_0$ ,  $b$  and  $c$  characteristic parameters of the solution are studied. They depend on the temperature, concentration of the solution, the nature of the polymer and solvent.

### 2. Materials

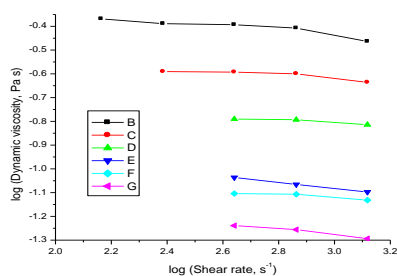
The physico-chemical properties of copolymer hydrogenated poly (isoprene-co-styrene) data sheet: physical state – solid, form – white solid blocks, colour – compressed crumbs, odourless, flashpoint > 150°C, insoluble in water, is not material hygroscopic, stable, density (15°C) – 0.272 g.cm<sup>-3</sup> and none hazardous decomposition. The properties oil

SAE 10W is: form - homogeneous liquid, yellow-brown, odor - characteristic, density (15°C) – 0.875 - 0.910 kg/m<sup>3</sup>, kinematics viscosity to 40°C - 90 cSt, kinematics viscosity to 100°C - 8 cSt, dynamic viscosity (20°C) - 65 cP, viscosity index – 70 -100, solubility in organic solvents, petroleum, fat, water-insoluble, flash point > 200°C, melting point - (-10) ÷ (-15)°C, amount of coke – 0.03 – 0.5%. The SAE 10W oil is predominantly paraffin. Solutions concentrations 3 %, 6 %, 10 % and 12 % of copolymer hydrogenated poly (isoprene-co-styrene) were obtained by continuous mixing at room temperature for several weeks.

The apparatus used for plotting curves rheological concentrates is a rotation viscometer (Rheotest) RV 550 type coaxial cylinder sensor and VH<sub>1</sub>. Viscometer was connected to a thermostat to raise the temperature of the sample. Cylinder S<sub>1</sub> was used for the constant is 5.67 and worked with a speed of copolymer concentrates were studied in the temperature range 40 – 90°C and shear rates between 3.3 and 1312 s<sup>-1</sup>.

### 3. Results and discussion

The Figure 1 shows variation logarithm dynamic viscosity with logarithm shear rate for 3% copolymer hydrogenated poly(isoprene-co-styrene) solution concentration of throughout the temperature range that was studied solution.



**Fig. 1.** Dependence log dynamic viscosity versus log shear rate 3 % solution concentrated at temperatures: B – 40°C, C – 50°C, D – 60°C, E – 70°C, F – 80°C and G – 90°C

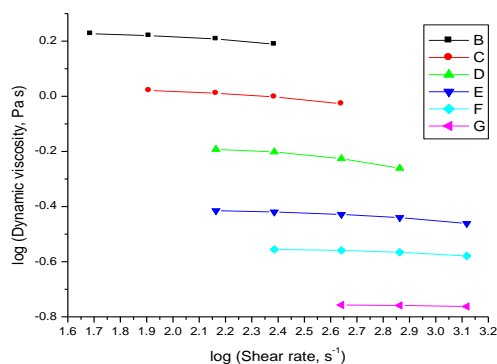
The graph shows that of the logarithm of dynamic viscosity decreases with increasing the logarithm of shear rate at all temperatures.

Table 1 the temperature range that was studied at 3% copolymer hydrogenated poly

(isoprene-co-styrene) solution parameter values obtained by fitting polynomial of the lines obtained correlation coefficients determined for each right.

As shown in Table 1  $\log \eta_0$  parameter is variable values, the lowest value is at most 80°C and at 70°C. These values depend on the structure copolymer hydrogenated poly (isoprene-co-styrene) and its behavior at elevated temperatures. The parameter b has only negative value at 70°C and the highest value at 80°C. The parameter c has the highest value it shows at 70°C and lowest temperature of 90°C. Correlation coefficients have values close to unity in the temperature range 60°C – 90°C and the value of one to the other temperatures.

The Figure 2 shows dependence logarithm dynamic viscosity with logarithm shear rate to 6% copolymer hydrogenated poly (isoprene-co-styrene) solution concentration.



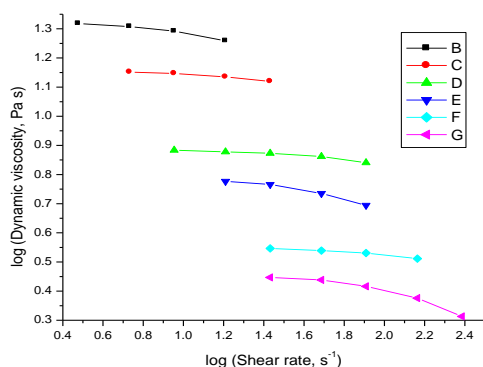
**Fig. 2.** Dependence log dynamic viscosity versus log shear rate 6% solution concentrated at temperatures: B – 40°C, C – 50°C, D – 60°C, E – 70°C, F – 80°C and G – 90°C

The lines obtained for the 6% of copolymer hydrogenated poly (isoprene-co-styrene) solution concentration is substantially parallel to the axis of the corresponding logarithm of the shear rate. Only at 60°C slope is much larger than the other temperatures at which the solution was studied.

Table 2 temperature range that was studied at 6% copolymer hydrogenated poly (isoprene-co-styrene) solution parameter values obtained by fitting polynomial of the lines obtained correlation coefficients determined for each right.

The parameter values  $\log \eta_0$  has positive values only at 40°C and the other values are negative in the temperature range 50°C – 90°C which was studied at 6 % copolymer hydrogenated poly (isoprene-co-styrene) solution. The parameter b is variable values but the lowest value at 90°C and largest at 60°C. The parameter c is variable values, the lowest value being at 60°C. Correlation coefficients have values close to unity at all temperatures has been studied solution which demonstrates that math equation describes quite well the rheological behavior of the 6 % of copolymer hydrogenated poly (isoprene-co-styrene) solution concentration.

Figure 3 shows dependence logarithm dynamic viscosity with logarithm shear rate to 10% copolymer hydrogenated poly (isoprene-co-styrene) strength solution.



**Fig. 3.** Dependence log dynamic viscosity versus log shear rate concentrated solution 10 % at temperatures: B – 40°C, C – 50°C, D – 60°C, E – 70°C, F – 90°C and G – 90°C

As seen in chart logarithm of dynamic viscosity decreases with increasing shear rate logarithm of the concentration for 10% solution of the copolymer hydrogenated poly (isoprene-co-styrene).

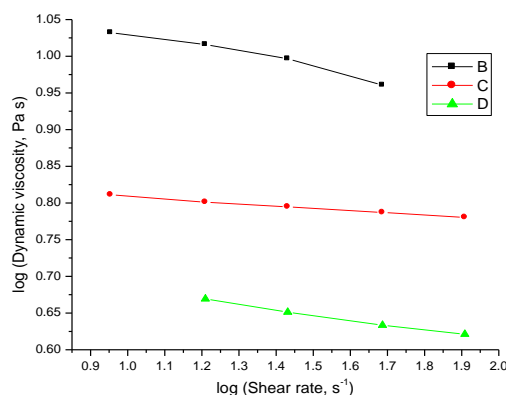
At 90°C slope has the highest value compared to the other temperatures at which the solution was studied.

Table 3 temperature ranges that was studied solution at 10 % of copolymer hydrogenated

poly (isoprene-co-styrene), parameter values obtained by fitting polynomial of the lines obtained correlation coefficients determined for each right.

As shown in Table 3 parameter  $\log \eta_0$  decreases with increasing temperature solution of 10 % concentration of copolymer hydrogenated poly (isoprene-co-styrene). Parameter b increases with increasing solution temperature. The parameter c is negative; the lowest value is at 90°C and highest at 60°C. The correlation coefficients have values close to unity at all temperatures at which the solution could be studied copolymer concentration of 10 % hydrogenated poly (isoprene-co-styrene).

Figure 4 shows dependence logarithm dynamic viscosity with logarithm shear rate to 12 % copolymer hydrogenated poly (isoprene-co-styrene) solution concentration solution.



**Fig. 4.** Dependence log dynamic viscosity versus log shear rate for 12 % concentrated solution at temperatures: B – 70°C, C – 80°C and D – 90°C

As shown in Figure 4 solution at 12 % of copolymer hydrogenated poly (isoprene-co-styrene) was studied at high temperatures is very astringent. Dependence of the logarithm of dynamic viscosity by logarithm of the shear rate decreases with increasing temperature and shear rate, the slope has the largest solution at 70°C.

**Table 1.** The temperature, value of parameters of described by equation (1) and coefficient correlation for 3 % solution concentrated

Temperature, °C	Value of parameters of the described by equation (1)			Correlation coefficient, R <sup>2</sup>
	log $\eta_0$	b	c	
40	-0.8834	0.4594	-0.1037	0.9420
50	-1.4883	0.7088	-0.1396	0.9855
60	-1.8703	0.7973	-0.1471	1.0000
70	-0.5793	-0.2109	0.0143	1.0000
80	-2.3967	0.9533	-0.1756	1.0000
90	-2.2015	0.7710	-0.1539	1.0000

**Table 2.** The temperature, value of parameters of described by equation (1) and coefficient correlation for 6 % concentrated solution

Temperature, °C	Value of parameters of the described by equation (1)			Correlation coefficient, R <sup>2</sup>
	log $\eta_0$	b	c	
40	0.0852	0.1812	-0.0577	0.9982
50	-0.1641	0.2142	-0.0614	0.9992
60	-0.7286	0.5088	-0.1207	0.9999
70	-0.6061	0.1824	-0.0436	0.9987
80	-0.7803	0.1908	-0.0405	0.9999
90	-0.8818	0.0971	-0.0189	1.0000

**Table 3.** The temperature, value of parameters of described by equation (1) and coefficient correlation for 10 % concentrated solution

Temperature, °C	Value of parameters of the described by equation (1)			Correlation coefficient, R <sup>2</sup>
	log $\eta_0$	b	c	
40	1.3023	0.0766	-0.0927	0.9986
50	1.1314	0.0650	-0.0512	0.9999
60	0.8364	0.0939	-0.0476	0.9869
70	0.5937	0.3222	-0.1412	0.9999
80	0.4626	0.1282	-0.0487	0.9962
90	0.0840	0.4872	-0.1637	0.9979

**Table 4.** The temperature, value of parameters of described by equation (1) and coefficient correlation for 12 % concentrated solution

Temperature, °C	Value of parameters of the described by equation (1)			Correlation coefficient, R <sup>2</sup>
	log $\eta_0$	b	c	
70	0.9949	0.1154	-0.0804	0.9992
80	0.8516	-0.0480	0.0057	0.9984
90	0.8155	-0.1536	0.0272	0.9999

Table 4 temperature range that was studied solution at 12 % copolymer hydrogenated poly

(isoprene-co-styrene), parameter values obtained by fitting polynomial of the lines obtained

correlation coefficients determined for each right.

As shown in Table 4 parameter  $\log \eta_0$  decreases with increasing temperature solution of 12 % concentration of copolymer hydrogenated poly (isoprene-co-styrene). The parameter b is variable values in the range of temperatures at which the solution was studied, the lowest value being at 90°C and largest at 70°C. The parameter c is set to the smallest value is at most 70°C and at 90°C. The correlation coefficients have values close to unity at all temperatures at which the solution could be studied of 12 % copolymer hydrogenated poly (isoprene-co-styrene) concentration.

#### 4. Conclusion

In this article we studied the rheological behavior of concentrated solutions copolymer hydrogenated poly (isoprene-co-styrene) at temperatures between 40 and 90°C and shear rates between 3 and 1312 s<sup>-1</sup>. The rheology of solutions of concentration 3 %, 6 %, 10 % and 12 % are affected by temperature, shear rate, shear stress and the nature of the polymer and the solvent. Empirical relationship of dependence of logarithm of dynamic viscosity by logarithm of shear rate accurately describes the rheological behavior of these concentrated solutions of copolymer hydrogenated poly (isoprene-co-styrene).

#### References

- Masao D, Molecular dynamics and rheological properties of concentrated solutions of rodlike polymers in isotropic and liquid crystalline phases. *Journal of Polymer Science: Polymer Physics Edition*, 1981;19: 243.
- Doi M, Edwards SF, Dynamics of concentrated polymer systems. Part 4.—Rheological properties. *Journal of the Chemical Society, Faraday Transactions 2: Molecular and Chemical Physics*, 1979; 75: 38-54.
- Kuzuu NY, Rheology of star polymers in concentrated solutions and melts. *Journal of Polymer Science: Polymer Letters Edition*, 1980;18(12):775-780.
- McKee MG, Wilkes GL, Colby RH, Long TE, Correlations of solution rheology with electrospun fiber formation of linear and branched polyesters. *Macromolecules*, 2004;37(5): 1760-1767.
- Sebastian JM, Lai C, Graessley WW, Register RA, Steady-shear rheology of block copolymer melts and concentrated solutions: Disordering stress in body-centered-cubic systems. *Macromolecules*, 2002; 35(7): 2707-2713.
- Osaki K, Kurata M, Experimental appraisal of the Doi-Edwards theory for polymer rheology based on the data for polystyrene solutions. *Macromolecules*, 1980;13(3): 671-676.
- Doi M, Edwards SF, Dynamics of concentrated polymer systems. Part 1.—Brownian motion in the equilibrium state. *Journal of the Chemical Society, Faraday Transactions 2: Molecular and Chemical Physics*, 1978;74: 1789-1801.
- Leonov AI, Nonequilibrium thermodynamics and rheology of viscoelastic polymer media. *Rheologica acta*, 1976;15(2): 85-98.
- Yasuda KY, Armstrong RC, Cohen RE, Shear flow properties of concentrated solutions of linear and star branched polystyrenes. *Rheologica Acta*, 1981; 20(2): 163-178.
- Prud'homme RK, Wu G, Schneider DK, Structure and rheology studies of poly (oxyethylene-oxypropylene-oxyethylene) aqueous solution. *Langmuir*, 1996;12(20): 4651-4659.
- Senff H, Richtering W, Temperature sensitive microgel suspensions: Colloidal phase behavior and rheology of soft spheres. *The Journal of chemical physics*, 1999;111(4): 1705-1711.
- Cassagnau P, Payne effect and shear elasticity of silica-filled polymers in concentrated solutions and in molten state. *Polymer*, 2003;44(8): 2455-2462.
- Adams N, Lodge AS, Rheological properties of concentrated polymer solutions II. A cone-and-plate and parallel-plate pressure distribution apparatus for determining normal stress differences in steady shear flow. *Philosophical Transactions of the*

- Royal Society of London. Series A, Mathematical and Physical Sciences, 1964; 256(1068): 149-184.
14. English RJ, Gulati HS, Jenkins RD, Khan S A, Solution rheology of a hydrophobically modified alkali-soluble associative polymer. *Journal of Rheology* (1978-present), 1997; 41(2): 427-444.
  15. Doublier JL, Launay B, Rheology of galactomannan solutions: comparative study of guar gum and locust bean gum. *Journal of Texture Studies*, 1981;12(2): 151-172.
  16. Jørgensen EB, Hvidt S, Brown W, Schillén, K, Effects of salts on the micellization and gelation of a triblock copolymer studied by rheology and light scattering. *Macromolecules*, 1997;30(8): 2355-2364.
  17. Xu J, Palmer A, Wirtz D, Rheology and microrheology of semiflexible polymer solutions: actin filament networks. *Macromolecules*, 1998;31(19): 6486-6492.
  18. Uppuluri S, Keinath SE, Tomalia DA, Dvornic PR, Rheology of dendrimers. I. Newtonian flow behavior of medium and highly concentrated solutions of polyamidoamine (PAMAM) dendrimers in ethylenediamine (EDA) solvent. *Macromolecules*, 1998;31(14): 4498-4510.
  19. Shashkina JA, Philippova OE, Zaroslov YD, Khokhlov AR, Pryakhina TA, Blagodatskikh IV, Rheology of viscoelastic solutions of cationic surfactant. Effect of added associating polymer. *Langmuir*, 2005; 21(4): 1524-1530.
  20. Ketz Jr RJ, Prud'homme RK, Graessley W W, Rheology of concentrated microgel solutions. *Rheologica acta*, 1988;27(5): 531-539.
  21. Böhm N, Kulicke WM, Rheological studies of barley (1→3)(1→4)- $\beta$ -glucan in concentrated solution: mechanistic and kinetic investigation of the gel formation. *Carbohydrate research*, 1999;315(3):302-311.
  22. Edsman K, Carlfors J, Petersson R, Rheological evaluation of poloxamer as an in situ gel for ophthalmic use. *European journal of pharmaceutical sciences*, 1998;6(2):105-112.
  23. Kern F, Zana R, Candau SJ, Rheological properties of semidilute and concentrated aqueous solutions of cetyltrimethylammonium chloride in the presence of sodium salicylate and sodium chloride. *Langmuir*, 1991;7(7): 1344-1351.
  24. Bhatia SR, Mourchid A, Joanicot M, Block copolymer assembly to control fluid rheology. *Current opinion in colloid & interface science*, 2001;6(5): 471-478.
  25. Lodge TP, Xu X, Ryu CY, Hamley IW, Fairclough JPA, Ryan AJ, Pedersen JS, Structure and dynamics of concentrated solutions of asymmetric block copolymers in slightly selective solvents. *Macromolecules*, 1996;29(18): 5955-5964.
  26. Saeed, D-K, Shahin Z., Y., The Relationship between Real Exchange Rates and Oil Prices in Iran: Evidence from M-TAR Model, *Magnt Research Report*, 2014;2(Special Issue): 911-918.