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Research Article

EXPERIMENTAL STUDY OF RHEOLOGICAL PROPERTIES OF VISCOELASTIC FLUIDS

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ABSTRACT

The rheological analysis of the polymer solutions is studied experimentally using a cone-plate rheometer. The rheograms obtained for various forms of stress show that these solutions have a non-Newtonian character very marked and their behavior is perfectly marked by a rheological model type Ostwald de Waele or power- law. The evolution of the rheological characteristics of these solutions is studied as a function of the temperature, concentration and the age of the organic solute. Detailed analysis of the relationships governing this development highlights the emergence of simple correlations between consistency and behavior index generally are considered independent

Keywords: Experimental study; Viscoelastic fluid; Polyacrylamide; Cone-plate rheometer; Rheological properties

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1. INTRODUCTION

Rheology is not resumed at, as everybody often think in viscosity measurement. It is a wide studying domain that concerns to the mechanical properties of materials and a set of divers experiences as well as flow tests such as creep, relaxation or oscillation experiences so called dynamics. These oscillation experiences, generally effort the most valuable and accurate information of the material being studied. The elaboration and utilization of new fluids in industry does not forcefully follow the classical theory of Newton law, the importance of practical problems generated due to the fluids studies lead to the non-Newtonian behavior few years ago. Rheology is a universal science opened on several industries among which food industry, cosmetic, medicine, pharmaceutical...etc. It studies a whole range of behaviors from elastic behavior to purely viscous behavior. In the later, two different types of fluids are separated; Newtonian fluids and non-Newtonian fluids.

2. EXPERIMENTAL TECHNIQUES

The study of rheological properties and viscoelastic characteristics of fluids in this work is carried out using Rheometer Carri-Med CS 100. the functioning of the rheometer is entirely controlled by computer, that give possibility of being used classically in order to establish the rheograms of fluids samples in continued shear flow, or dynamically in an oscillation flow. It allows to determine the threshold of fluids flow starting from transitional flows, its creep properties. The rheometer Carri-Med CS 100 version 4.3 is an imposed stress rheometer with torque ranging from 1μN.m to 10^{-2} N.m, varying with velocity gradient of 10^{-5} s^{-1} to 5.10^3 s^{-1} (depend on utilized measurement device) and viscosity 2.5 10^{-2} mPa.s to 2.5 10^9 mPa.s as well as working angular velocity from 0 to 50 radians per second. The fluid sample disposed between the cone - plateau space. The tangential stress utilized depend on the geometry varies between 0.008 et 4.5 10^3 Pa. the volume of sample necessary to establish a rheogram for a cone of 2° et de 4 cm of diameter is also small ranges from 0.6 cm^3 to 2.4 cm^3.

The measurements were realized at 20°C with control of the shear velocity to not reach limits leading to turbulence.

For too small angles ψ, we can consider that the stress τ and the shear velocity $\dot{\gamma}$ are determined by the motion of fluids layer are constant in the entire sample.

$$M = 2\pi\tau \int r^2\, dr = \frac{2}{3}\pi R^3 \tau \quad (1)$$

$$\tau = \frac{3M}{2\pi R^3} \tag{2}$$

If the cone has a constant velocity N, the linear velocity of a radius 2πNr, the height of space between the cone and plateau of a radius r is r tgψ, so the shear velocity at radius r is:

$$\dot{\gamma} = \frac{2\pi r N}{r tg\psi} = \frac{2\pi N}{tg\psi}$$ If ψ is too small

tg ψ = ψ

$$\dot{\gamma} = \frac{2\pi N}{\psi} \tag{3}$$

The velocity gradient is independent to the cone radius, the angle ψ is in radians; thus we obtain the rheogram of sample. Among large possible behaviors for material under shearing stress, the rheometer CS 100 allows to study of; Newtonian and non-Newtonian viscous fluids, viscoelastic fluids simultaneously but with different degree, the viscous properties of fluid and elastic properties of solid. The rheological characterization of viscous fluids is done in continued regime that lead to determine flow curves. The viscoelastic characterization is made by creep test in transitional mode as well as dynamical test in oscillation mode. A constant torque was imposed on mobile which is can be varied step by step or progressively as time function and measure its corresponding rotational velocity ω. The transformation of physical scalar of fluids mechanic equations and boundary conditions of the problem lead to establishment of flow curves that perform the velocity gradient variation within the fluid in function of its undergoing shear stress.

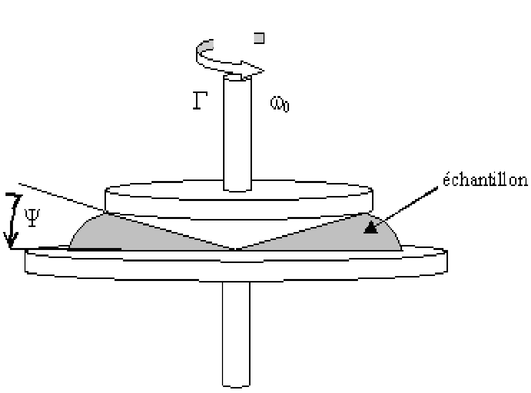

Fig.1. Cone-plate rheometer

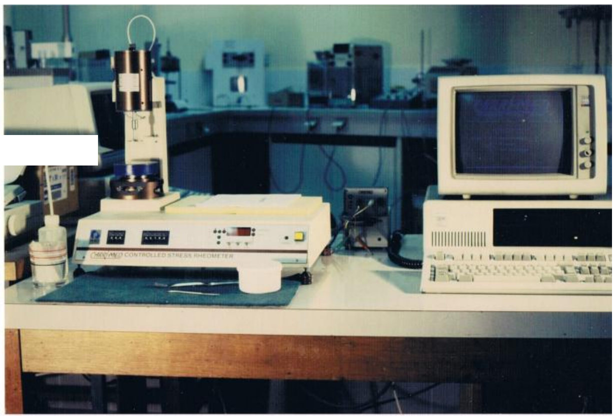

Fig.2. Experimental apparatus

Table 1. Characteristics of measuring systems

Geometry	Volume of sample (cm^3)	Air- gap (μm)
Cone 4 cm, 2deg	0.6	70
Cone 6 cm, 2deg	2.4	70

3. RESULT ANALYSIS

The rheological analysis shows the polyacrylamide solutions are threshol-plastic with a thixotropy more or less depend on the concentration, moreover they present an elastic effect. The obtained results with a rotational viscosimeter type plan cone with imposed stress has been presented by the Herschel-Bulkley model in a range of velocity gradient from 10^{-2} à 10^{3} s^{-1}.These results show as well the dependency of rheological parameters m, n and τ_0, of this model as function of the concentration of the solutions and operating temperature.

First of all, we assume in all cases that all fluids have pseudo-plastic behavior with behavior index $n < 1$.

In order to analytically present the plastic behavior of these solutions, we used the Herschel-Bulkley model that combine the plastic effect such as Bingham model with non-Newtonian behavior by power law for stresses above the threshold stress.

$$\tau = \tau_0 + m(\dot{\gamma})^n \quad \text{if} \quad \tau > \tau_0 \tag{4}$$

$$\dot{\gamma} = 0 \quad \text{if} \quad \tau < \tau_0 \tag{5}$$

The parameters τ_0, m and n of this model are given directly the software CS100 or calculated from the graph of these results in algorithmic coordinates.

The first qualitative observations are the following:

At constant temperature, the consistency factor m increases as the concentration increase, and for a constant concentration the consistency decreases as the temperature increases. On the other hand the structure index increases when the concentration increases.

According to these observations, we can conclude that:

The Ostwald consistency of fluids is highly influenced by the effect of temperature and its evolution is identical to the dynamic viscosity of the solvent.

The non-Newtonian character, as function of structure value index decreases while the concentration of solutions decreases which appears logic. The same coefficient comes close to the unity when the temperature grows and this seems to be more predictable.

4. RESULTS AND DISCUSSIONS

4.1. Influence of concentration on properties

The concentration range is 0.1 % to 2% of polyacrylamide solutions. After determination of the consistency index and fluid structure respectively m and n (figures 3and 4). The behaviors of polyacrylamide solutions are then sensitive to the evolution of the variation of concentration. At a given temperature, the consistency factor m increases with the increase of concentration, however the structure index discards with decrease from the unity. These results appear logic because of the augmentation of solute concentration, the percentage of coarse molecules inside the solution grows at the same proportion, and the non-Newtonian character takes place because it is resulted from the growth of these molecules.

Table 2. Rheological parameters measured at a temperature T= 20°C

C (%)	τ_0 (N/m^2)	m (Pa.s^n)	n (-)
0.1	0.03	0.37	0.416
0.2	0.18	0.66	0.374
0.4	0.49	1.53	0.324
0.6	0.76	5.31	0.240
0.8	2.24	8.21	0.219
1.0	2.98	10.4	0.205
1.5	10.3	24.9	0.209
2.0	15.4	37.9	0.229

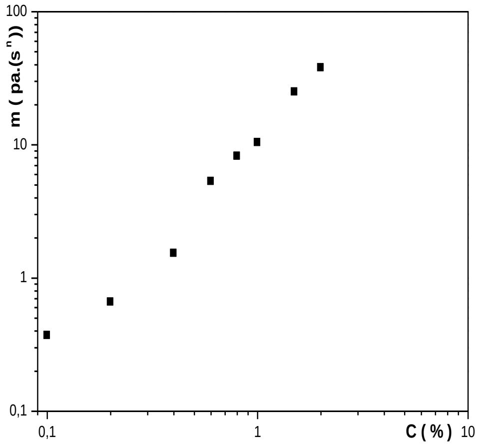

Fig.3. Evolution of the consistency factor in function of the concentration for polyacrylamide solutions

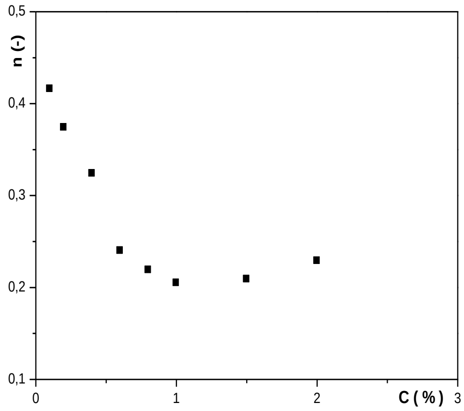

Fig.4. Influence of concentration on power law index for polyacrylamide solutions

4.2. Influence of the temperature on the rheological properties

We carried out our experiences at temperature between 15° and 35° C, this range corresponds our operating conditions. The rheograms illustrated of the figures 5 and 6 characterize the role of temperature. The representations of consistency variations as function of temperature (figure 5) lead to the following observations:

For a given concentration, logm is a linear function of inverse absolute temperature. The representative lines of these variations for different concentrations are increasing and parallel to each others.

On the figure 6 we have reported as an example the evolutions of structure index as function of temperature in normal coordinates, for three types of solutions; at the opposite this log m and non m that is taken as inverse function of temperature. For each of these two representations and for each concentration, the experiment points are correctly lined up, this is valid for all studied solutions.

Table 3. Influence of temperature on rheological parameters

C (%)	0.6	0.7	0.8
T (°c)	m (Pas^n)	m (Pas^n)	m (Pas^n)
20	5.31	6.36	8.21
25	4.67	6.18	7.84
30	4.10	5.74	7.25
35	3.94	4.41	6.78

C (%)	0.6	0.7	0.8
T (°c)	n (-)	n (-)	n (-)
20	0.22	0.19	0.18
25	0.25	0.21	0.20
30	0.27	0.25	0.23
35	0.31	0.28	0.27

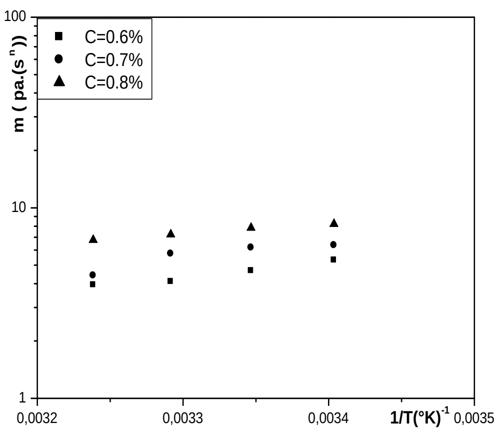

Fig.5. Evolution of consistency factor as a function of fluid temperature

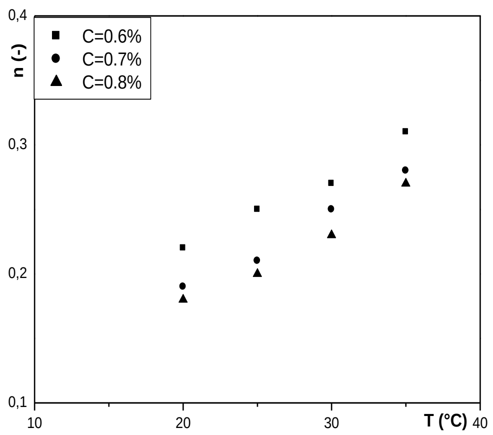

Fig.6. Evolution of power law index depending on the fluid temperature

4.3. Influence of ageing on the rheological parameters

By the solution age, it has to intend the time interval, t that flow between the preparation moments at the measuring instant. To put in evidence the influence of this parameter, we carried out a sweep of fluid age (solution of polyacrylamide) at a concentration of 1%, from time zero to five months (150 days) after preparation. We have obtained the following results:

The examination of table 3 confirms that:

- the threshold of stress τ_0 decreases when the age of solution increases.
- the consistency index m increases with the solution age.
- the behavior index of fluid n increases slightly when the solution age increases.

Table 4. Influence of ageing of solution on rheological parameters

time (days)	τ_0 (N/m^2)	m (Pa.s^n)	n (-)
0	2.980	10. 4	0.205
150	0.3790	13.60	0.287

4.4. Influence of reactive on rheological parameters

The rheology of polyacrylamide solution evolves when the coloration-discoloration method is used. The presented values in the table show the concentration effect of iodine and thiosulfate on the rheological parameters of polyacrylamide solution of 1.5%.

Table 5. Influence of reactive on rheological parameters

Product	τ_0 (N/m^2)	m (Pa.s^n)	n (-)
Pure PAA	10.30	24.95	0.2090
PAA+ Iodine	0.1492	10.15	0.3793
PAA+ Iodine+ Thiosulfate	0.1042	5.207	0.4090

5. CONCLUSION

The rheological analysis shows that the polyacrylamide solution follow the power law with thixotropy more or less depends on the concentration. The obtained results by mean of rotational rheometer plan-cone with imposed stress are represented by the Ostwald model within velocity gradient range of 10^{-2} to 10^3 s^{-1}. These results illustrate the dependence of rheological parameters m and n of this model as function of the concentration of polyacrylamide solution. In addition analysis show that polyacrylamide solution is plastic with thixotropic threshold according to the concentration and represent and elasticity behavior. The obtained results by mean of rotational rheometer plan-cone with imposed stress are represented by the Herschel-Bulkley model within velocity gradient range of 10^{-2} to 10^3 s^{-1}. The results show the dependence of rheological parameters m, n and τ_0 of this model as function of the concentration of the solutions and the operating temperature.

5. REFERENCES

[1] Bellet D., Sengelin M., Caractéristiques rhéologiques de solutions non- newtoniens : influence de la température et de la concentration, C.R. Acad. Sc. Paris, 273, 126- 128 (1971).

[2] Bellet D., Sengelin M., Quelques expériences sur le comportement non-newtonien de liquides organiques, XIIèmes journées de l'hydraulique, rapport 2, 1-8, Paris (1972).

[3] Ketz R.J., Prud'homme R.K., Graessley W.W., Rheology of concentrated microgel solutions, Rheologica Acta, 27, 531539 (1988).

[4] Youcefi A., Experimental study of viscoelastic fluid flow around two-blade impeller in a stirred vessel, PhD Thesis, National Polytechnic Institute, Toulouse (France), (1993).

[5] Platt H.A., Chuba J.V., Kaplan H.S., Initial studies of the temperature-viscosity

relationship of humain plasma and serum biorheology, 15, 29-35, (1978).

[6] Magnin A., Piau J.M., Cone-and plate rheometry of yield stress fluids study of an aqueous gel, J. Non- Newt. Fluid Mech., 36, 85-108 (1990).

[7 Ben Azouz K., Depuis D., Bekkour K., Rheological characterizations of dispersions of clay particules in viscoelastic polymer solutions, App. Rheol., 20, 13041 (2010).

[8] Ferry J.D., Viscoelastic properties of polymers, 3ème édition, John Wiley, New York (1980).

[9] Couaraze G., Grossiord J.L., Initiation à la rhéologie, Tech. et Doc. Lavoisier (1983).

[10] Grossiord J.L., Méthodes de caractérisations rhéologiques : applications aux polymères, Entropie, 159, 53-58 (1990).

[11] Coussot P., Grossiord J.L., Comprendre la rhéologie de la circulation du sang à la prise du béton, EDP Sciences Editions, Paris, 191-195 (2002).

[12] Barnes H.A., Hutton J.F., Walters K., An introduction of rheology, Rheology series, 3, New York (1989).

[13] Darby R., Viscoelastic fluids: an introduction to their properties and applications, Marcell Dekker, 9, USA, (1976).

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