

1 **Flow, dynamic viscoelastic and creep properties of a biological polymer**
2 **produced by *Sphingomonas sp.* as affected by concentration**

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9 **Abstract**

10 In this work, the influence of the concentration on the flow behaviour, dynamic
11 viscoelastic and creep properties of diutan gum in aqueous solution was investigated.
12 Diutan gum is a biopolymer which belongs to the sphingans group. To know its
13 rheological properties and its microstructure as a function of the concentration is directly
14 related to the current and future applications of this biological polymer. Mechanical
15 spectra showed a crossover point between G' and G'' which changed as a function of
16 diutan gum concentration. A master curve for the frequency dependence on the η^* was
17 obtained. The creep compliance results made it possible to deduce the yield stress value
18 and they were fitted to Burgers model. A shear-thinning behaviour was exhibited by
19 diutan gum aqueous solutions, which was fitted to the Carreau-Yasuda model. Higher
20 G' , G'' , τ_0 and η_0 values and lower ω_c , J_e^0 , $\dot{\gamma}_c$ and n values were obtained by increasing
21 the gum concentration, it is being possible to modulate the viscoelasticity, viscosity and
22 shear resistance as a function of concentration. A more complex structure with stronger

23 entanglements between macromolecules of diutan was obtained when the concentration
24 of diutan increases.

25

26 **Keywords**

27 Diutan gum, Rheology, Viscoelasticity, Creep compliance, Yield stress

28

29 **1.- Introduction**

30 Diutan gum is an anionic biopolymer whose backbone structure consists of a repeated
31 units of D-glucose, D-glucuronic acid, D-glucose and L-rhamnose) and its molecular
32 weight ranges from 2.88 to 5.18 MDalton [1, 2]. It is obtained from *Sphingomonas* sp.
33 ATCC53159 by aerobic fermentation and it belongs, therefore, to the sphingans group
34 [3]. As a consequence of its capability to modify the rheological properties of the aqueous
35 solutions, nowadays it has applications in various fields. Long Xu et al. [4] reported the
36 effect of temperature and salinity on the rheological properties of diutan gum solutions
37 from 10^{-3} wt% to 0.4 wt % concentration range. In this work [4], the authors concluded
38 that there was no influence of the temperature and salinity conditions on the physical
39 properties of these biopolymer solutions. This fact makes the use of diutan gum very
40 interesting in applications where the environmental conditions could be extremely harsh,
41 such as in the case of tertiary petroleum recovery [4]. Furthermore, diutan gum can be
42 used as a viscosity-enhancing admixture in concrete formulation. In the concrete industry,
43 these admixtures are usually used to improve the rheological properties of materials based
44 on cement, principally the viscosity. In this way, the grouts containing diutan gum exhibit
45 a shear thinning behaviour, and as a consequence, the mixtures show high viscosity at

46 low shear, presenting an apparent Newtonian viscosity, whereas the fluidity at high shear
47 rate improves due to a decrease in the viscosity [5].

48 Furthermore, recently Carmona et al. [6] studied the effect of shear and temperature on
49 the microstructure of 0.5 wt% diutan gum aqueous solutions.

50 Nevertheless, the literature concerning diutan gum is scarce and there is not an exhaustive
51 study of the influence of diutan gum concentration on its linear viscoelastic and flow
52 properties, as it is done in this work.

53 From an engineering point of view, the study of the steady state properties of materials is
54 most rewarding. However, numerous materials exhibit an elastic behaviour along with
55 their steady state properties, and therefore, in order to characterize them rheologically, it
56 is necessary to use a method which studies the combination of elastic and viscous
57 behaviours of materials. Unsteady state tests supply a method to study viscoelastic
58 substances, and for this purpose, transient and oscillatory measurements are the most used
59 tests. In this work, creep compliance measurements have been carried out to obtain
60 information that can be useful in assessing phenomena taking place in industrial
61 processes. In these tests, the sample is submitted to a constant shear stress for a certain
62 time and the evolution of the strain is observed. Data obtained from these experiments
63 can be related to industrial applications influenced by the effects of gravity, such as
64 sedimentation or levelling [7]. In addition, knowledge concerning creep compliance could
65 be helpful in the study of construction and building materials. For this purpose, several
66 researchers have used this test in order to predict the thermal cracking of asphalt concrete
67 used in flexible pavements [8, 9, 10].

68 To get better insights into the properties and microstructure of the diutan gum dispersions,
69 the influence of its concentration (0.1,0.2,0.3,0.4 and 0.5 wt%) on the viscoelastic linear

70 and flow properties been evaluated in this paper by means of small amplitude oscillatory
71 shear tests, creep compliance measurements and the figures of flow curves.

72 **2. Materials y Methods**

73 *2.1. Materials*

74 Diutan gum of type KELCO-VISTM DG kindly supplied by CP Kelco (San Diego, USA)
75 has been used. The diutan gum was studied in the 0.1-0.5 wt % concentration range and
76 0.5 wt % NaCl, provided by Panreac, was employed as source of cations. This
77 concentration range was selected because the most relevant property of the biopolymers
78 is their capability to modify the flow behaviour in aqueous solutions at low
79 concentrations. The concentrations studied are similar to those used in other biopolymers
80 such xanthan gum or gellan gum [11- 14]. In order to preserve the diutan gum solution,
81 0.1 wt % sodium azide (Panreac) was introduced into the formulation. In addition, water
82 milli-Q was utilized. Each system studied was denoted as MX, being X the wt % of diutan
83 gum contained in the sample.

84 *2.2. Methods*

85 *2.2.1. Diutan gum solution preparation.*

86 Batches of 600 g of diutan gum solution were prepared. For this purpose, diutan gum
87 powder was added to a vessel containing NaCl, sodium azide and milli-Q water. The
88 mixture was stirred constantly at 700 rpm for 5 hours by means of an Ika-Visc MR-D1
89 homogenizer (Ika, Germany) and a coulex impeller. The diameter ratio between the
90 impeller and vessel was 0.85. The diutan gum solution was then submitted to a
91 temperature of 80°C for one hour while stirring at 700 rpm was maintained using the same
92 equipment. Finally, the water lost by evaporation was replaced.

93 Samples were kept at 4.5°C for at least 48 hours before their characterization.

94

95 *2.2.2. Rheological measurements*

96 All rheological measurements, except flow curves, were performed by means of an AR-
97 2000 controlled-stress rheometer (TA Instruments, Crawley, United Kingdom) assisted
98 by a sensor system consisting of a rough parallel plate with a diameter of 60 mm (PP60R)
99 and a measuring gap of 1 mm. Temperature was set at $25\text{ }^{\circ}\text{C} \pm 0.1\text{ }^{\circ}\text{C}$ with a Peltier system
100 aided by a Thermo Scientific circulator.

101 Flow curves were determined with a Haake-Mars controlled-stress rheometer (Thermo
102 Scientific, Karlsruhe, Germany) connected to a Phoenix circulator (Thermo-Scientific) at
103 $25\text{ }^{\circ}\text{C}$. Measurements were carried out using, as a sensor system, a coaxial cylinder (inner
104 diameter 20.0 mm, outer diameter 21.7 mm, cylinder length 30.0 mm) (Z20) with a treated
105 surface.

106 *2.2.2.1. Time sweep tests*

107 In order to avoid any effects of the mechanical history of the samples after placing them
108 the sensor system, the equilibration time was determined. For this purpose, time sweeps
109 at 1 Hz and 0.5 Pa were performed for 2 hours at $25\text{ }^{\circ}\text{C}$.

110 Equilibration times were obtained using a first-kinetic equation which has been used to
111 fit the G' values in recovery systems such as suspensions with xanthan gum as stabilizer
112 [15].

113
$$G' = G_0' + (G_{\infty}' - G_0') [1 - \exp(-k \cdot t)^m] \quad (1)$$

114 where G' is the elastic component, G_0' is the G' value for zero recovery time obtained
115 from the equation (1), G_{∞}' is the G' value for a complete structural recovery, k is a kinetic

116 coefficient and m is a fitting parameter indicating the kinetic order which has been made
117 equal to 1 in this particular case.

118 The values of equilibration time were in the 1000-2900 s range (data not shown).
119 However, to prevent samples from drying, it was decided to apply an equilibration time
120 of 900 s in all systems studied.

121 *2.2.2.2. Determination of linear viscoelastic range (LVR)*

122 Before carrying out mechanical spectra studies stress sweep tests were performed,
123 ranging from $8 \cdot 10^{-3}$ to 10 Pa at 3 different frequencies (0.1, 1 and 3 Hz) in order to
124 determine the linear viscoelastic range.

125 *2.2.2.3. Frequency sweep test*

126 Once the linear viscoelastic region was established, frequency sweep tests were
127 performed in the 15-0.05 rad/s range at constant shear stress within LVR.

128 *2.2.2.4. Time sweep tests*

129 Oscillatory shear time tests were used to complete the mechanical spectra at frequency
130 values below 0.5 rad/s. These measurements were performed in the $5.5 \cdot 10^{-3}$ - $8 \cdot 10^{-3}$ rad/s
131 range at fixed shear stress values, which guaranteed the LVR.

132 *2.2.2.5. Creep compliance tests*

133 Creep compliance measurements were performed while maintaining a constant stress,
134 which ranged from 0.01Pa to 2.5Pa for 2 hours.

135 In order to model the viscoelastic behaviour of the sample studied, creep compliance
136 results have been fitted to Burgers model. This model consists of Maxwell and Kelvin
137 elements connected in series. To obtain a better representation of data, in Burgers model
138 two Kelvin elements have been included. Therefore, Burgers model was described as:

139
$$J = \left(\frac{1}{G_0}\right) + \left(\frac{1}{G_1}\right) \left(1 - \exp\left(-\frac{t}{\lambda_{ret1}}\right)\right) + \left(\frac{1}{G_2}\right) \left(1 - \exp\left(-\frac{t}{\lambda_{ret2}}\right)\right) + \frac{t}{\eta_0} \quad (2)$$

140 Where J is the compliance as a function of time, $\frac{1}{G_0}$ is equal to J_0 which is instantaneous
 141 compliance, at $t=0$, $\frac{1}{G_1} = J_1$; $\frac{1}{G_2} = J_2$, λ_{ret} is the retard time which is the time needed to
 142 reach maximum deformation, η_0 is the Newtonian viscosity in the steady state. The two
 143 exponential elements of equation (2) represent viscoelastic behaviour described by the
 144 two Kelvin elements. In this way, $\frac{1}{G_0} = J_0$ is the purely elastic response, and t/η_0 is the
 145 Newtonian response when the steady state is reached. In the measurements carried out in
 146 the linear viscoelastic range, the steady state compliance, J_e^0 , is equal to the following
 147 equation [7].

148
$$J_e^0 = J_0 + J_1 + J_2 \quad (3)$$

149 In addition, when the linear portion of the creep curves is fitted to a linear equation, it is
 150 possible to determine the value of J_e^0 from the interception and $1/\eta_0$ from the curve slope.

151 *2.2.2.6. Steady shear flow tests*

152 The measurements were performed in the 2.0 - 15 Pa shear stress range by a step-wise
 153 procedure, with 30 points and 300s at each shear stress to reach the steady-state regime.

154 In all rheological tests, in order to prevent the effects of mechanical history, the sample
 155 was kept in the measuring gap and in a quiescent state for the equilibration time of 900
 156 seconds to permit stress relaxation before beginning the test. Every measurement was
 157 performed at least 4 times on fresh samples.

158 *2.2.2.7. ANOVA ONE WAY study.*

159 ANOVA ONE WAY method has been employed to determine the occurrence of
160 significant differences among the obtained results. In order to fulfill this purpose,
161 OriginPro 8 software was used.

162

163 **3. Results and discussion**

164 *3.1. Determination of linear viscoelastic range (LVR)*

165 Stress sweep tests were performed at 0.1Hz, 1 Hz and 3 Hz to estimate the linear
166 viscoelastic range (LVR). Firstly, elastic component (G') values above the viscous
167 component (G'') values were observed in each sample studied (data not shown). In
168 addition, as the stress increases two regions can be clearly differentiated: a) the so-called
169 linear viscoelastic region with constant values of elastic modulus and viscous modulus
170 and b) a non-linear region where both viscoelastic functions start to decrease. It should
171 be noted that the inception of the non-linear response was identified by a slight fall in G'
172 accompanied by a clear decrease in G'' .

173 The value of stress from which G' and G'' values are no longer constant is known as the
174 critical stress, τ_c , and it corresponds to the stress that leads to the first non-linear changes
175 in the structure [16]. Its value indicates the degree of association between macromolecules
176 [17]. The ANOVA ONE study demonstrated regardless of the frequency studied, by
177 increasing the concentration of diutan gum aqueous solutions, the values of τ_c increase
178 (Table 1), indicating the entanglements between the macromolecules in solution are
179 stronger and, therefore, the shear resistance.

180

181 *3.2. Frequency sweep tests*

182 Mechanical spectra demonstrated (Figure 1) that the diutan gum solutions containing 0.5
183 wt % NaCl exhibited viscoelastic properties at all concentrations studied. In order to avoid
184 the drying of M0.5 sample, the data at smaller frequencies were obtained by means of
185 time sweep tests. In the mechanical spectra of all samples there was a predominance of
186 the elastic component, G' , over the viscous component, G'' , at higher frequencies.
187 However, a crosspoint was observed at low frequency, ω_c , which progressively shifted to
188 lower frequencies with increasing gum concentration (Table 2) as supported the ANOVA
189 ONE WAY study. The crossover point is inversely related to the terminal relaxation time
190 of the samples, λ , so that, as the concentration of diutan gum in the sample increases, the
191 time necessary for its structure to relax is greater. The behaviour observed can be
192 attributed to the formation of a network or incipient gel based on a limited number of
193 entanglements, characterized by long relaxation times. As the gum concentration
194 decreases, the degree of entanglements decreases as well as the relaxation time.
195 Therefore, we observed a change in behaviour from more solid-like viscoelastic
196 properties to more marked liquid-like viscoelastic properties by decreasing the gum
197 concentration.

198 In order to normalize the analysis, a master curve for the frequency dependence on the
199 complex viscosity at the reference concentration of 0.3 wt % was obtained (Figure 2). As
200 can be observed in Figure 2, the results exhibited an acceptable superposition in the whole
201 range of frequencies studied. Similar superpositions have been found with other
202 biopolymers but using G' and G'' rather than η^* [18, 19].

203 The values of vertical and horizontal shift factors are shown in Table 2. Interestingly, the
204 vertical shift factor (F_{η^*}) decreases by increasing the gum concentration. Conversely, the
205 horizontal shift factor, F_{ω_c} , increases. The concentration dependence of this last factor can

206 be described by a power law, $F_{oc} \propto c^{3.3}$ ($R^2=0.95$). Cuvelier and Launay [20, 21] for
207 xanthan solutions, which also belongs to the sphingans group, above the overlap
208 concentration found an stronger concentration dependence ($c^{7.4}$).

209 *Creep compliance tests*

210 Figure 3 exhibits the creep compliance test results at all shear stresses applied for the
211 sample containing 0.2 wt % diutan gum. In Figure 3, the test data has been expressed in
212 terms of the creep compliance function, which is $J(t) = \gamma/\tau$, where γ is the shear strain
213 and τ is the constant shear stress applied. As can be observed, compliance curves obtained
214 in the range of shear stress applied from 0.05Pa to 0.1 Pa overlap as a consequence of
215 carrying out the tests at shear stresses within the viscoelastic linear range [6]. An increase
216 in shear stress value of 0.4Pa provoked the inception of non-linear viscoelastic behaviour
217 of the sample. Similar results were obtained when testing the other samples studied.

218 Figure 4 shows the steady state compliance, J_e^0 , and Newtonian viscosity, η_0 , as a function
219 of the shear stress applied for all diutan gum concentrations studied. This figure displays
220 a significant decrease of the J_e^0 and η_0 values from a critical value of shear stress. In
221 addition, the fitting parameters of Burgers model (equation (2)) did not fulfill the linear
222 condition expressed by equation (3) for shear stress values higher than the critical shear
223 stresses. For these reasons, it could be deduced that the inception of the non-linear
224 viscoelastic range has been reached and, therefore, those shear stress values could be
225 considered to be the yield stress values (τ_0). That is, the shear stress value which has to
226 be exceeded so that the sample can flow at significant values of shear rate. This fact
227 reveals the possibility of determining the yield stress by creep compliance tests. In recent
228 studies, the yield stresses of materials with very shear thinning behaviour were obtained
229 by creep-recovery-creep measurements [12, 13]. The yield stress values for samples

230 M0.2, M0.3, M0.4 and M0.5 are respectively 0.1Pa, 0.25Pa, 0.5Pa and 0.7Pa. As can be
231 observed, there was an increase in yield stress values as a function of the diutan gum
232 concentration, which is in agreement with the results obtained in oscillatory tests. The
233 more structured the sample, the higher the stress threshold to initiate the flow. These
234 results were supported by ANOVA ONE study.

235 Additionally, an increase in the η_0 values and a decrease in J_e^0 values with diutan gum
236 concentration can be observed in Figure 4. These results are in agreement with the
237 occurrence of a stronger viscoelastic structure by increasing the concentration of gum in
238 solution and, consequently, with a structure more resistant to flow, as was observed from
239 oscillatory measurements.

240 *3.3. Steady shear flow tests*

241 Figure 5 shows flow curves of the samples studied (full symbols). Also included in this
242 figure are the viscosity values obtained by means of creep compliance tests. In this way,
243 viscosities values at exceptionally small shear rate values in which the time needed to
244 achieve steady state would be extremely large are incorporated. These results have been
245 shown in Figure 5 as open symbols.

246 A shear-thinning behaviour was exhibited for all systems studied, which is typical of
247 polymeric molecules aligned in the flow direction as the shear rate increases. As a
248 consequence of this, a decrease in the polymeric interactions between adjacent chains
249 occurs. This behaviour was fitted to the Carreau-Yasuda model (equation (4) [22]):

250

$$251 \quad \eta = \eta_{\infty} + \frac{\eta_0 - \eta_{\infty}}{\left(1 + \left(\frac{\dot{\gamma}}{\dot{\gamma}_c}\right)^p\right)^{\frac{1-n}{p}}} \quad (4)$$

252 Where η_0 is the zero shear viscosity, η_∞ is infinite shear viscosity, $\dot{\gamma}_c$ is critical shear rate
253 related to the inception of structural collapse, n is the index flow and p is a fitting
254 parameter.

255 The fitting parameters shown in Table 4 indicate that, as the gum concentration increased,
256 the viscosity value increased. Similar behaviour was observed in other gums such as
257 xanthan gum, Sterculia apetala gum or Prosopis juliflora gum [17, 23]. Higher
258 concentration of gum improves the entanglements of molecular chains and therefore
259 increases the viscosity. A typical behaviour was found for the critical shear rate, $\dot{\gamma}_c$, since
260 it decreased with diutan gum concentration. As expected, the lowest $\dot{\gamma}_c$ was shown by the
261 most concentrated dispersion since this parameter is related to the longest relaxation time
262 of the system. It should be remarked that the longer the terminal relaxation time, the
263 higher the solid-like viscoelastic properties exhibited by the sample. The flow index, n ,
264 showed a tendency to decrease as the gum concentration was increased on account of the
265 increasing non-Newtonian properties caused by the greater structural complexity of gum
266 dispersions.

267

268 **4. Conclusions**

269 This work presents a study of linear viscoelastic properties and flow behaviour of diutan
270 gum solutions in concentrations ranging from 0.1 wt % to 0.5 wt %. All of them showed
271 a linear viscoelastic range which increased with the diutan gum concentration. In addition,
272 mechanical spectra exhibited G' values above G'' and a crosspoint between both
273 functions at low frequency, which was a function of the diutan gum concentration. The
274 crossover frequency, related to the relaxation time, decreased as the diutan gum
275 concentration increased, indicating that the sample structure needs a longer time to relax
276 as its concentration increases. Moreover, a superposition of the mechanical spectra in

277 term of complex viscosity as a function of the frequency demonstrated that the samples
278 containing from 0.1 wt % to 0.5 wt % diutan gum showed a similar structure.

279 On another hand, creep compliance data were well fitted to the Burgers model. The fitting
280 parameters and the plot of creep compliance function made it possible to determine the
281 onset of the non-linear viscoelastic region for all the systems studied, and this is related
282 to the yield stress value. This value of shear stress increased with the diutan gum
283 concentration. Additionally, these tests, along with flow curves, made it clear that these
284 samples presented a shear-thinning behaviour. Subsequently, the viscosity values
285 determined from creep tests at low shear stress were used to complete the flow curves in
286 order to obtain more real values of the zero-shear viscosity. The final flow curves
287 achieved from creep measurements and flow curves fitted well to the Carreau-Yasuda
288 model. The fitting parameters obtained supported those obtained from the creep
289 compliance test. Zero-shear viscosity increased with the diutan gum concentration.
290 Consequently, the critical shear rate and flow index showed smaller values as the gum
291 concentration increased.

292 All rheological results are in agreement with the occurrence of a sample structure more
293 resistance to shear and flow which has higher viscoelastic properties and viscosity with
294 increasing concentration of diutan gum. Therefore, It is possible to modulate the
295 rheological properties of diutan gum aqueous solutions modifying its concentration.
296 Results obtained are very interesting for industrial applications of diutan gum not only as
297 viscosity enhancer but also as stabilizer agent. Furthermore, these applications can be
298 developed at very low concentrations.

299

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304

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369

370 Tables

371 Table 1. Determination of dynamic linear viscoelastic region at studied frequencies (0.1,
 372 1 and 3 Hz.

	$\tau_c(\text{Pa})_{0.1 \text{ Hz}}$	$\tau_c(\text{Pa})_{1 \text{ Hz}}$	$\tau_c(\text{Pa})_{3 \text{ Hz}}$
M0.1	0.21±0.03	0.24±0.02	1.30±0.42
M0.2	0.68±0.19	0.67±0.07	0.20±0.01
M0.3	1.41±0.27	1.84±0.23	1.79±0.42
M0.4	2.31±0.44	> 3	2.72±0.26
M0.5	> 3	> 3	>3

373

374

375 Table 2. Determination of crossover points and vertical and horizontal shift factors to get
 376 the master curve at studied diutan gum concentrations. T=25°C.

	$\omega_c \text{ (rad/s)}$	$\lambda \text{ (s)}$	$G' = G'' \text{ (Pa)}$	F_{ω_c}	$\eta^*_{\text{corte}} \text{ (Pa}\cdot\text{s)}$	F_{η^*}
M0.1	0.340 ± 0.010	2.94	0.20±0.01	0.12	0.82	41.00
M0.2	0.085±0.003	11.8	0.53±0.01	0.45	8.75	3.82
M0.3	0.039±0.001	27.9	0.96±0.02	1	33.42	1
M0.4	0.017±0.002	58.8	1.26±0.07	2.30	106.9	0.31
M0.5	0.006±0.002	166.7	1.49±0.09	5.75	331.2	0.09

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381 Table 3. Fitting parameters of the Carreau-Yasuda equation for diutan gum solutions at
 382 studied concentrations. SD stands for standard error of fitting parameters.

	η_{∞} (Pa·s)	η_0 (Pa·s)	$SD\eta_0$ (Pa·s)	γ_c (s ⁻¹)	$SD\gamma_c$ (s ⁻¹)	p	SDp	n	SDn	R^2
M0.5	10 ⁻³	2528.6	174.4	0.0015	7·10 ⁻⁴	0.52	0.10	0.11	-	0.998
M0.4	10 ⁻⁴	1106.3	33.4	0.0013	4·10 ⁻⁴	0.95	-	0.17	-	0.998
M0.3	10 ⁻⁴	281.0	8.05	0.005	7·10 ⁻⁴	0.65	-	0.17	-	0.999
M0.2	10 ⁻⁴	44.5	0.08	0.018	2·10 ⁻⁴	0.85	-	0.18	5·10 ⁻³	0.997
M0.1	2.2·10 ⁻⁴	3.72	0.20	0.07	5·10 ⁻³	1.5	-	0.21	0.01	0.993

383

384 **Table captions.**

385 Table 1. Determination of dynamic linear viscoelastic region at studied frequencies (0.1,
 386 1 and 3 Hz.

387 Table 2. Determination of crossover points and vertical and horizontal shift factors to get
 388 the master curve at studied diutan gum concentrations. T=25°C.

389 Table 3. Fitting parameters of the Carreau-Yasuda equation for diutan gum solutions at
 390 studied concentrations. SD stands for standard error of fitting parameters.

391

392 **Figure Captions**

393 Figure 1. Influence of diutan gum solution on the mechanical spectra. It is included the
 394 points obtained from frequency sweep tests (close symbols) and those obtained from time
 395 sweep tests (open symbols). T=25°C.

396 Figure 2. Master curve for the frequency dependence on the complex viscosity taking as
 397 the reference the sample containing 0.3 wt % diutan gum. T=25°C.

398 Figure 3. Creep compliance test results at all shear stresses applied for the sample
 399 containing 0.2 wt % diutan gum. T=25°C.

400 Figure 4. Influence of diutan gum solution on J_e^0 (A) values and η_0 values (B). T=25°C.

401 Figure 5. Influence of diutan gum solution on the viscosity values obtained from flow
402 curve measurements (close symbols) and creep compliance tests (open symbols).
403 $T=25^{\circ}\text{C}$.

404

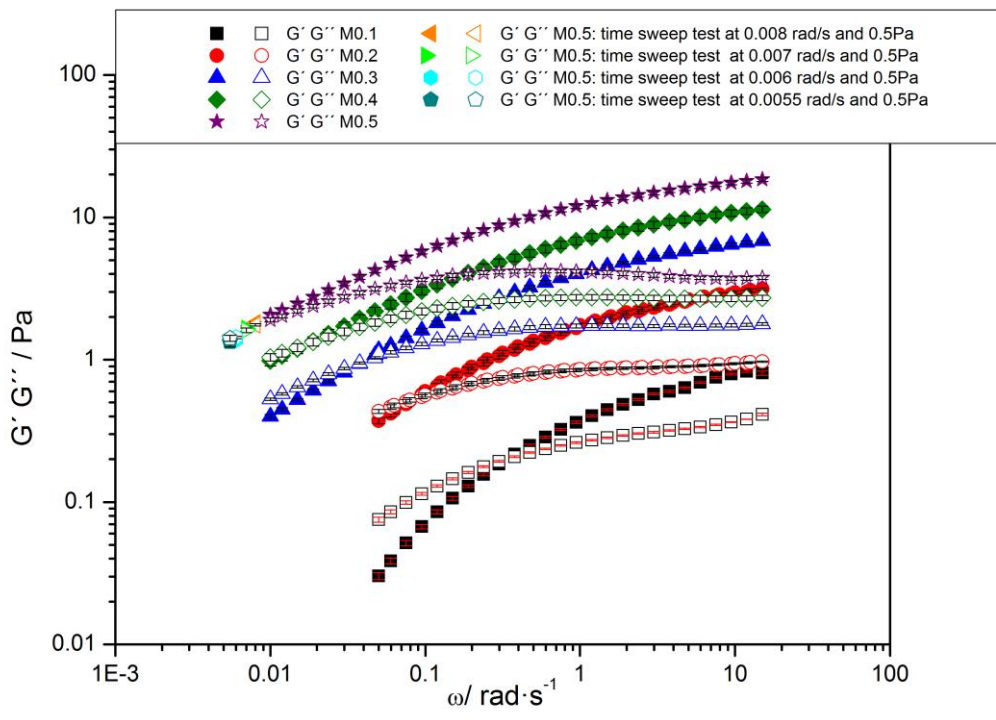


Figure 1. Influence of diutan gum solution on the mechanical spectra. It is included the points obtained from frequency sweep tests (close symbols) and those obtained from time sweep tests (open symbols). $T=25^{\circ}\text{C}$.

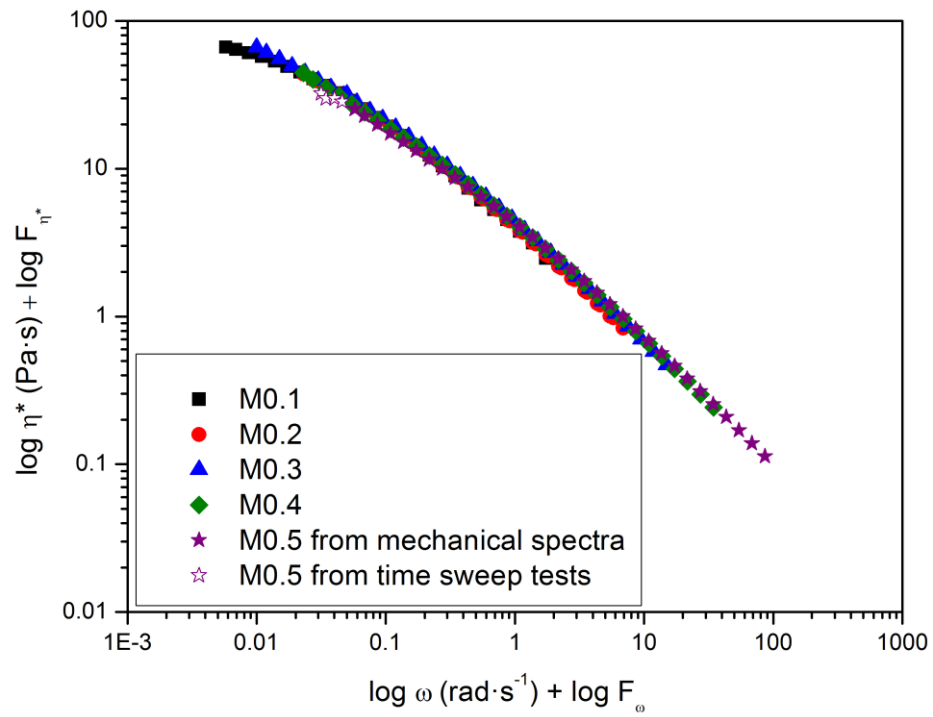


Figure 2. Master curve for the frequency dependence on the complex viscosity taking as the reference the sample containing 0.3 wt % diutan gum. $T=25^{\circ}\text{C}$.

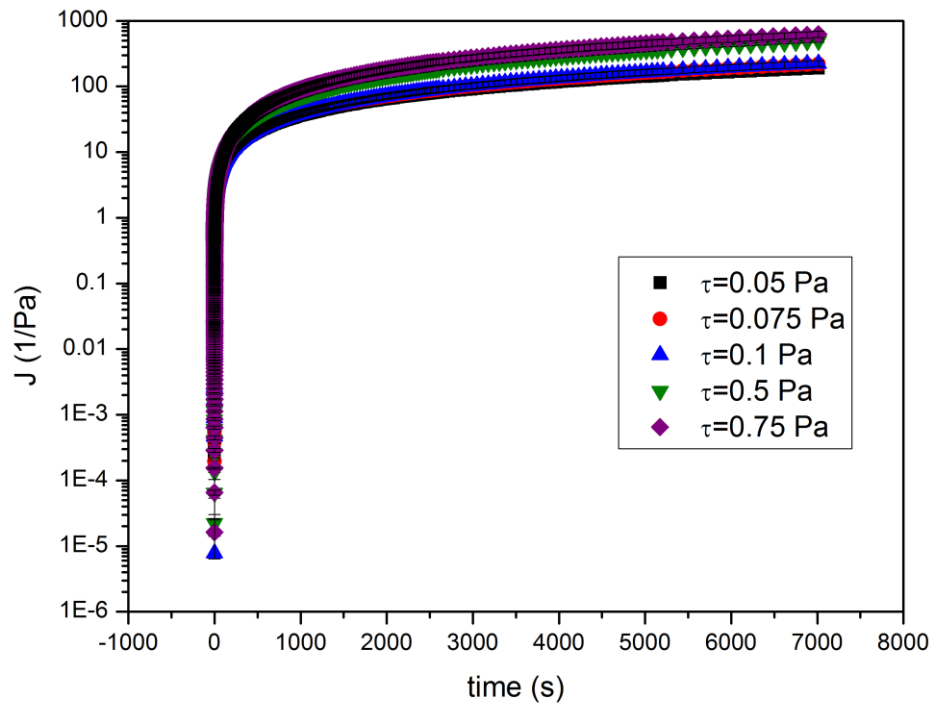


Figure 3. Creep compliance test results at all shear stresses applied for the sample containing 0.2 wt % diutan gum. $T=25^\circ\text{C}$.

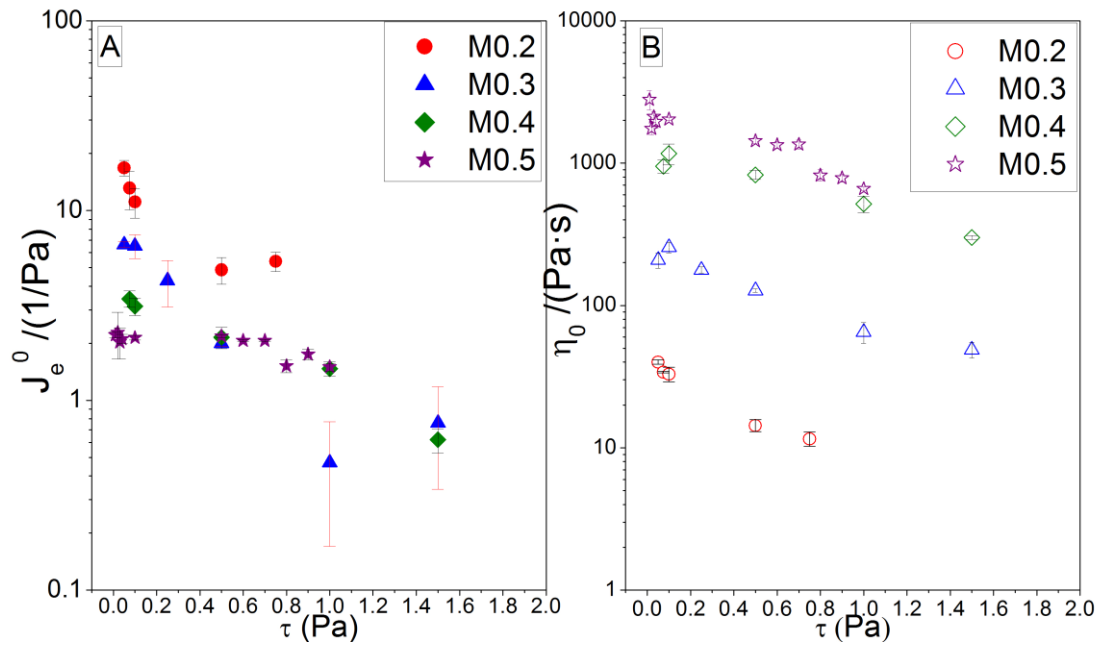


Figure 4. Influence of diutan gum solution on J_e^0 (A) values and η_0 values (B). $T=25^\circ\text{C}$.

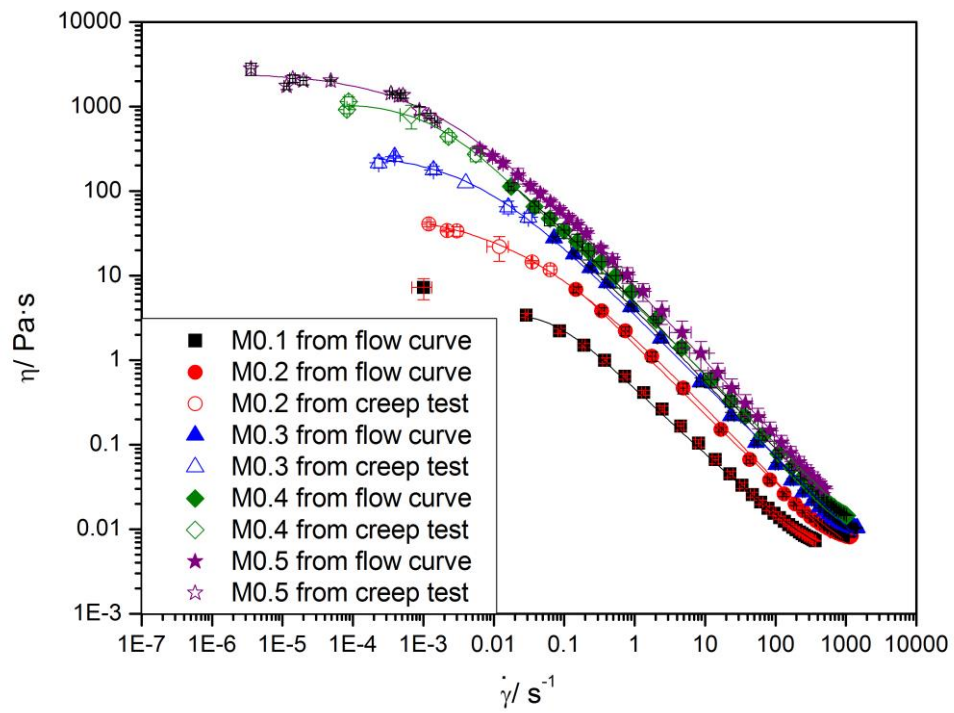


Figure 5. Influence of diutan gum solution on the viscosity values obtained from flow curve measurements (close symbols) and creep compliance tests (open symbols). T=25°C.