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Effect of some physical and chemical properties on the interactions between biopolymers and anionic surfactants

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ABSTRACT

The combination of systems containing biopolymers surfactants is found in diverse formulated products such as wastewater treatment, food, drugs (pharmaceuticals), cosmetics, paints, detergents, pesticides and also in processes such as polymer synthesis, wastewater treatment and enhanced oil recovery. In this work, we examine the effect of surfactant: sodium dodecyl sulphate (SDS) on solutions containing biopolymer: xanthan gum, alkali and oil by interfacial tension (IFT), conductometric and rheological measurements. To this end, the method of experiments planning was adopted. Previous study on the conductivity profiles of SDS/Xanthan gum and salt systems had shown the existence of interaction and the curves presented linearity as expected. The results show an important effect on surface tension, IFT, conductometric and rheological properties on the studied systems; also, they indicate an important action of surfactant SDS, oil and biopolymer greatly influences IFT.

Keywords: Xanthan gum; Sodium dodecyl sulphate; Interfacial tension; Conductivity; Stress; Shear rate

1. Introduction

The application of micellar systems and the effect of electrolytes on the biopolymers nature's interactions have a significant role in many practical situations, in which polymers and surfactants are present at the same time; this is the case in food, pharmaceutical, cosmetics and oil industries. The basic idea behind using polymers is to reduce aqueous phase mobility and to increase its viscosity [1,2]. It is known that solutions containing polymers and surfactants can give rise to molecular interactions that may affect their rheological and physicochemical properties [3]. These interactions also display features that depend on polymer and surfactant electrical charges and hydrophobicity, polymer conformation and flexibility and the presence of additives such as salts. It is generally accepted that the hydrophobic character of both polymer and surfactant is responsible of interactions [4]. The nature of these interactions has been investigated for several decades and is extensively documented [5]. They are still poorly understood, but significant variations of the physicochemical and rheological properties of these systems are observed. Most study in this field focus on complexes of anionic surfactants with polymers [6–8].

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The investigation of the polymer–surfactant interactions can be done in two ways. In the first one, the polymer is considered as being the substance influenced by the surfactant, in the second way, the surfactant is considered as being the substance influenced by the polymer. In the first case, the surfactant is adsorbed on the polymer sites which disturb the formation of the surfactant micelles. Alternatively, in the second case, the association of surfactant molecules with macromolecules facilitates the phenomenon of micellization [9,10]. The examination of the evolution of the physicochemical and rheological properties of such systems, according to the chemical nature and component concentrations, makes it possible to establish relations between these factors and the system responses such as surface tension, conductivity, viscosity, stress and shear stress.

Response surface method (RSM) was proposed to determine the influences of individual factors and their interactive influences. RSM is a statistical technique for designing experiments, building models, evaluating the effects of several factors and searching optimum conditions for desirable responses [11]. The main advantage of this method of other statistical experimental design methods is the reduced number of experiments trials needed to evaluate multiple parameters and their interactions [12]. Recently, this method has been used to evaluate and determine optimum parameters in different processes [13,14].

In the past, researchers used one-factor-at-a-time experimental method, which not only consumed more time and more cost but also neglected the effect of interaction between factors. Although traditional orthogonal method is capable of considering a few factors at the same time, it cannot get a functional expression between the factors and response values. RSM is a statistical method that uses quantitative data from appropriate experiments to determine multiple regression equations between the factors and experimental results [11]. The main advantage of this method of other statistical experimental design methods is the reduced number of experiments trials needed to evaluate multiple parameters and their interactions [12].

This work is a contribution to the comprehension of this phenomena, to this end, sodium dodecyl sulphate (SDS), sodium chloride and xanthan gum and dodecane effects on the physicochemical (conductivity and surface tension) and rheological properties: stress and shear stress of aqueous solutions were studied using a RSM, in particular, a D-optimal design. Surface tension and conductivity measurements were used to detect the influence of the polymer on the surface activity of the surfactant. Changes in physical properties were investigated by rheological techniques. These physicochemical and rheological properties were used as factors and responses, respectively, for the model of experimental design.

2. Experimental

2.1. Materials

Xanthan gum was purchased from Rhodia (France); SDS (99%) (Analytical grade) was purchased from Fluka (Switzerland); Sodium chloride (NaCl of reagent grade, 99%) was supplied by Panreac chimica (Spain). n-Dodecan ($C_{12}H_{26}$) (analytical grade) was purchased from FLUKA. Kerosene (density and viscosity of 775 kg/m^3 and $8.10^{-6}\,m^2/s$) and crude oil (density 806 kg/m^3 and viscosity 22×10^{-3} Pa.s.) were obtained from Algerian oil field. These products were used because they gave conclusive results [15–22].

2.2. Preparation of mixtures and methods

Surface and interfacial tensions (IFTs), critical micelle and critical aggregation concentrations of mixtures were obtained using a surface tension method and measured with a Du Noüy tensiometer, model 70545 (CSC Scientific Co. USA). The conductivity measurements were obtained using an "Inolab conductivity meter level" (Germany) with (cell constant: 0.475 cm^{-1}). Rheological measurements were obtained using CSL2 rheometer from TA instruments

Polymer dispersions were prepared by dissolution of the polymer in water under mild stirring at room temperature. After 24 h, different amounts of surfactant and salt were added to the polymer solutions. The surfactant was dissolved under slow mixing in a helix mixer (Heidolph RZR 2020, Germany). The surfactant concentrations were chosen to be equal, higher or smaller than the critical micelle concentration (CMC) of the surfactant. However, the polymer concentrations were chosen to give variations in the solution rheological and turbidimetric properties [23].

2.3. Experimental design

Aqueous solutions containing SDS, sodium chloride, xanthan gum and dodecan were investigated by ionic conductivity, viscosimetric, rheological and surface and IFT methods. A preliminary experimental study was performed to evaluate the effect of the mixture compositions on the surface behaviour of the mixed polymer/surfactant systems under different solution conditions. An experimental design using RSM was then applied to assess factors interactions and empirical models regarding the physicochemical responses variables (i.e. conductivity, turbidity and surface tension). In this work, MODDE 6 software is used. The main effects of the four independent factors: SDS (x_1), xanthan (x_2), NaCl (x_3) and dodecan (x_4) concentrations were investigated using in particular a D-optimal design. The results show an important effect of the factors on responses. The D-optimal criterion was developed to select design points in a way that minimizes the variance associated with the estimates of specified model coefficients [24]. Analysis of variance (ANOVA) showed high-variance coefficient (R^2) values, thus, ensuring a satisfactory adjustment of the second-order regression model with the experimental data. The variables were coded according to equation:

$$X_i = \frac{U_i - U_i^0}{\Delta U_i} \tag{1}$$

where X_i is the independent variable coded value; U_i is the independent variable real value; U_i^0 is the independent variable real value on the centre point and ΔU_i is the step change value.

Table 1 presents the levels of predictor variables tested following D-optimal design of experiments.

2.4. Establishment of the experimental matrix

The matrix type of experience, which response to the strategy of minimizing error in the estimation of coefficients and the overall error, is D-optimal. The matrix contains 16 trials of various areas of variation factors to minimize the error in the centre and estimate the standard deviation of the natural values. The following table shows the matrix of experiments on this strategy (Table 1), in which factors (X_i) in weight % and responses (Y_i) are defined as follows:

Table 1
Matrix of coded values

Experience N°	n-Dodecan	SDS	Xanthan gum	NaCl
1	1	−1	−1	−1
2	−1	1	−1	−1
3	1	1	−1	−1
4	−1	−1	1	−1
5	1	−1	1	−1
6	−1	1	1	−1
7	−1	−1	−1	1
8	1	1	−1	1
9	1	−1	1	1
10	−1	1	1	1
11	1	1	1	1
12	−1	0	0	0
13	0	−1	0	0
14	0	0	−1	0
15	0	0	0	1
16	0	0	0	0

X_1: mass concentration of n-Dodecan which varies between [20 and 50%].

X_2: mass concentration of SDS which varies between [0.1 and 0.7%].

X_3: mass concentration of xanthan gum which varies between [0.1 and 0.5%].

X_4: mass concentration of NaCl ranges from [0.02 to 0.50%].

Y_1: shear rate (1/s), Y2: stress (N/m^2), Y3: IFT (mN/m), Y4: Conductivity (mS/cm).

3. Results

3.1. Statistical analysis

A first-order experimental design was first set up equation:

$$Y_i = b_0 + \sum_{i=1}^{3} b_i X_i \tag{2}$$

The observed results were analysed using first-order linear models. A lack of fit between predicted and experimental values led us to discard the first-order design. In fact, since the model validity bar is lower than 0.25, the lack of fit is significant and the model error is significantly larger than the pure error (reproducibility), this last, is always rather good ($R = 1 - (\mathrm{MS_{pureerror}}/\mathrm{MS_{total\ \ SS\ \ corrected}} > 098)$ but the standard deviation for the model error is much higher than of the replicate error. Whether, a true lack of fit should not be further considered.

The arrangements of D-optimal experiments are listed in Table 2, which include 16 sets of experiments. By using multiple regression analysis, the responses (conductivity, surface tension and viscosity) were correlated with the three design factors through the second-order polynomial equation:

$$Y_i = b_0 + \sum_{i=1}^{3} b_i X_i + \sum_{i=1}^{3} b_{ii} X_i^2 + \sum_{i=1}^{3} \sum_{j(\neq i)=2}^{3} b_{ij} X_i X_j \tag{3}$$

where b_o, b_i, b_{ii} and b_{ij} are constant regression coefficients of the model, while X_i and X_j are the independent variables. The statistical significance of the regression coefficients was determined by the Fisher, F-test ANOVA and the proportion of variance explained by the model obtained was given by the multiple coefficient of determination, R^2.

Table 2
Levels of independent variables in uncoded form and responses

Run	n-Dodecan (% wt.)	SDS (% wt.)	XG (% (wt.)	NaCl (% wt.)	Shear rate (1/s)	Stress (Pa)	Interfacial tension (mN/m)	Conductivity (mS/cm)
01	0.01	0.1	0.100	0.020	961.3	1.609	56	1.56
02	0.01	0.1	0.100	0.50	965.1	1.604	51	2.2
03	0.01	0.7	0.500	0.02	965.6	1.6	45	2.1
04	0.01	0.1	0.500	0.50	967	1.67	49.5	3.2
05	0.01	0.7	0.500	0.50	965.4	1.608	48	4.9
06	0.03	0.1	0.100	0.02	978.3	1.68	49	5.1
07	0.03	0.1	0.100	0.02	965	1.64	40	5.65
08	0.03	0.1	0.100	0.50	980.5	1.677	52	6.4
09	0.03	0.7	0.100	0.50	972	1.713	53	8.4
10	0.03	0.1	0.500	0.02	995	1.771	47	9.8
11	0.03	0.7	0.500	0.02	985	1.773	42.5	13.3
12	0.03	0.1	0.500	0.50	965	1.666	43	8.8
13	0.02	0.4	0.300	0.26	967.3	1.65	43.5	8.5
14	0.02	0.4	0.300	0.26	978	1.64	43	9.8
15	0.02	0.4	0.300	0.26	975	1.666	44	13.8
16	0.02	0.4	0.300	0.26	970	1.667	42	9

The determination of the coefficients of the polynomial model is performed by the selected method of multi-linear regression; the following histogram gives the values of $R^2$and Q^2 vs. the shear rate, the stress, the IFT and the conductivity. Fig. 1 shows the value and variance of the prediction model. The quality of the results obtained at the end of the adjustments is determined by the variance coefficient R^2 and the prediction coefficient Q^2. The first shows how the model explains the observed values. Plus, it is close to 1, the more the model is fitting (adequate). The second shows the predictive power of the model. Thence to 0.7, the model has good predictive power.

The quadratic regression model for shear rate (Y_1), stress (Y_2), IFT (Y_3) and conductivity (Y_4) in terms of coded factors are given by, Eqs. (4)–(7), respectively:

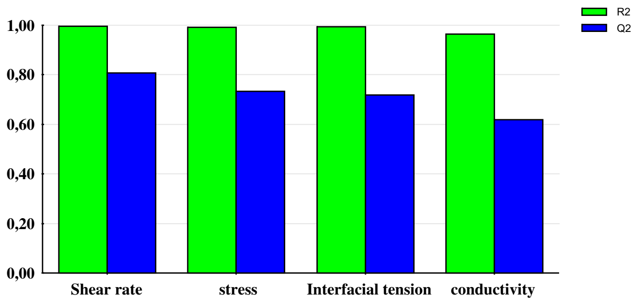

Fig. 1. Histogram of R^2 and Q^2 relative to the obtained results.

$$\begin{aligned}Y_1(1/s) = {} & 971.445 - 0.703165\,X_1 + 5.00819\,X_2 \\ & + 3.85327\,X_3 + 5.48586\,X_4 - 5.90081\,X_1^2 \\ & + 0.290192\,X_2^2 + 8.2127\,X_3^2 - 2.05401\,X_4^2 \\ & - 1.03456\,X_1X_2 - 1.84654\,X_1X_3 \\ & - 0.44703\,X_1X_4 - 0.146059\,X_2X_3 \\ & + 1.18321\,X_2X_4 - 0.140409\,X_3X_4\end{aligned} \tag{4}$$

$$\begin{aligned}Y_2(\mathrm{N/m^2}) = {} & 1.65663 - 0.00641906\,X_1 + 0.00775498\,X_2 \\ & + 0.0286741\,X_3 + 0.0300992\,X_4 \\ & - 0.000869905\,X_1^2 + 0.0102941\,X_2^2 \\ & + 0.0137513\,X_3^2 - 0.0163425\,X_4^2 \\ & + 0.0038814\,X_1X_2 - 0.00578064\,X_1X_3 \\ & + 0.00809565\,X_1X_4 - 0.00866001\,X_2X_3 \\ & + 0.00726638\,X_2X_4 + 0.0116911\,X_3X_4\end{aligned} \tag{5}$$

$$\begin{aligned}Y_3(\mathrm{mN/m}) = {} & 41.2768 + 0.78192\,X_1 - 1.6164\,X_2 \\ & - 1.759\,X_3 + 0.0667883\,X_4 + 1.89073\,X_1^2 \\ & + 0.810555\,X_2^2 + 0.0733177\,X_3^2 + 2.3664\,X_4^2 \\ & - 2.66089\,X_1X_2 - 1.8421\,X_1X_3 \\ & + 2.31621\,X_1X_4 + 0.681521\,X_2X_3 \\ & + 0.822952\,X_2X_4 + 0.441799\,X_3X_4\end{aligned} \tag{6}$$

$$\begin{aligned}Y_4(\mathrm{mS/cm}) = {} & 11.0512 + 0.29514\,X_1 + 0.919732\,X_2 \\ & + 1.29147\,X_3 + 1.8206\,X_4 - 1.96809\,X_1^2 \\ & - 1.41974\,X_2^2 + -0.414502\,X_3^2 \\ & - 0.419749\,X_4^2 + 0.15587\,X_1X_2 \\ & + 0.766734\,X_1X_3 - 0.108094\,X_1X_4 \\ & + 0.531818\,X_2X_3 + 0.480741\,X_2X_4 \\ & + 0.0829321\,X_3X_4\end{aligned} \tag{7}$$

The ANOVA for the models used to estimate the shear rate (N/m^2), the stress (Pa), the surface and the IFT (mN/m) and the conductivity (mS/cm), respectively, as a function of n-Dodecan, SDS, XG and NaCl concentrations are shown in Table 2.

The statistical significance of the second-order model was evaluated by the *F*-test ANOVA.

The ANOVA for the model used to estimate shear rate shows that the regression is highly significant of the model ($p = 0.197$) and presents a determination coefficient ($R^2 = 0.995$) explaining 99.5% of the validity in the response. The ANOVA for the model obtained for stress shows more significant of the model ($p = 0.257$) and presents a good determination coefficient ($R^2 = 0.992$) indicating that less than 1% of the total variations is not explained by the model. The value of the adjusted determination coefficient R^2 (adj) = 0.881 is also very high and indicates a high significance of the model [25]. For the IFT, the model presented a high-determination coefficient ($R^2 = 0.994$) explaining 99.4% of validity in the response. Finally, for the conductivity, the model presented a high-determination coefficient ($R^2 = 0.964$) explaining 96.1% of validity in the response.

3.2. Influence of some factors on the shear rate

The shear rate of mixtures containing SDS in the presence of various amounts (biopolymer, sodium chloride and n-dodecan) was determined with rheological method. The shear rate (1/s) vs. stress (N/m^2) of the samples was calculated using the following equation [26]:

$$\tau = \mu \cdot \dot{\gamma} \tag{8}$$

Table 3
ANOVA for the model regression representing the stress (Pa), the shear rate (N/m^2), the IFT (mN/m) and the conductivity (mS/cm), using coded values

	DF	SS	MS	*F*	*p*	SD
Shear rate (N/m^2)[a]						
Regression	14	1,244.25	88.875	15.4579	0.197	9.4274
Residual	1	5.750	5.750	–	–	2.3978
Lack of fit	1	–	–	–	–	–
Pure error	0	–	–	–	–	–
Total	16	1.512e + 007	945,287	–	–	–
Stress (Pa)[b]						
Regression	14	0.041076	0.002934	8.92452	0.257	0.0542
Residual	1	0.000328	0.000329	–	–	0.0181
Lack of fit	1	–	–	–	–	–
Pure error	0	–	–	–	–	–
Total	16	44.37	2.77356	–	–	–
Interfacial tension (mN/m)[c]						
Regression	14	318.155	22.7253	12.4199	0.219	4.76711
Residual	1	1.82976	1.82976	–	–	1.35268
Lack of fit	1	–	–	–	–	–
Pure error	–	–	–	–	–	–
Total	16	35,335.8	2208.48	–	–	–
Conductivity (mS/cm)[d]						
Regression	14	206.613	14.758	1.91235	0.518	3.84162
Residual	1	7.71723	7.71723	–	–	2.77799
Lack of fit	1	–	–	–	–	–
Pure error	0	–	–	–	–	–
Total	16	1,005.49	62.8429	–	–	–

[a] $R^2 = 0.995$, R^2 adj = 0.931.
[b] $R^2 = 0.992$, R^2 adj = 0.881.
[c] $R^2 = 0.994$, R^2 (adj) = 0.914.
[d] $R^2 = 0.964$, R^2 (adj) = 0.460.
DF—degree of freedom; SS—sum of squares; MS—mean square; *F*—Fisher test; *p*—probability; SD—standard deviation.

where τ is the stress and $\dot{\gamma}$ is the shear rate and μ is the dynamic viscosity. The stress expression is given by the following equation:

$$\tau = F/A \tag{9}$$

where τ is the shear stress, F is the force applied and A is the cross-sectional area.

Fig. 2 shows the isoresponse plots for shear rate at varying xanthan gum and n-Dodecan concentrations given by Eq. (4), the SDS and NaCl are held at its zero level plot (SDS = 0.4% wt. and NaCl = 0.26% wt). The shear rate values decrease with increasing XG and n-C_{12} concentrations (the maximum of shear rate (970.1 1/s) is obtained for n-C_{12} = 0.35(in coded values) which correspond to the concentration of n-C_{12} = 17.5% wt in natural values) and for XG = −0.1 in coded values (corresponding to 0.01%wt in natural values).

3.3. Influence of factors on the stress

The stress curves obtained from Eq. (5) and given by Fig. 3 gives the isoresponse plots at varying SDS and xanthan gum concentrations values, and at constants (nC_{12} = 35% and NaCl = 0.26% wt). The isoresponse curves show the effects of these varying concentrations while the two others were kept constant.

Fig. 3 represents the isoresponse plots for stress when the xanthan gum and SDS concentrations are varying, the n-Dodecan and NaCl are held at its zero level plot (n-Dodecan = 35% wt. and NaCl = 0.26% wt). The stress values decrease with decreasing XG concentrations (the minimum is obtained for (1.6513 N/m^2) at SDS constant value, and the stress values were kept practically constant when SDS concentrations changes for XG is kept constant.

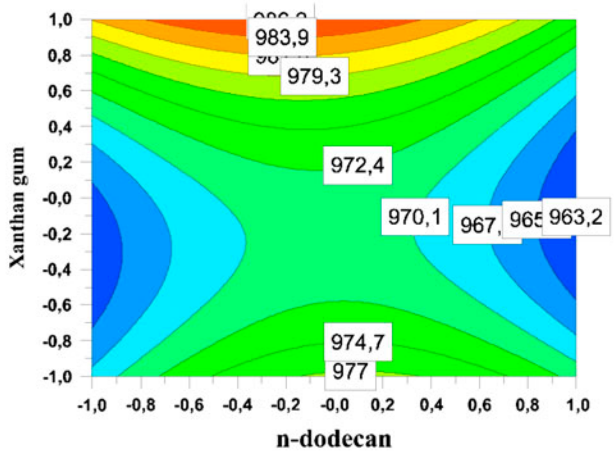

Fig. 2. Effect of XG and n-Dodecan concentrations on the Shear rate (N/m^2): Contour response plot (NaCl = 0.26% wt. and SDS = 0.4% wt.).

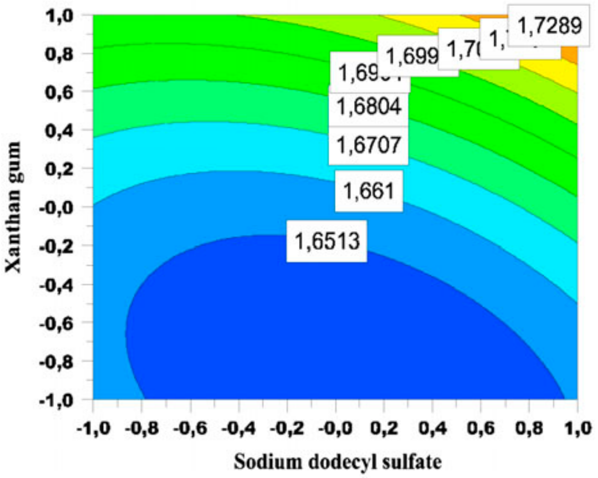

Fig. 3. Effect of Xanthan gum and SDS concentrations on the Stress (N/m^2): isoresponse plot (nC_{12} = 35% wt. and NaCl = 0.26% wt.).

3.4. Influence of factors on the IFT

The combined effect of polysaccharides and surfactants has been conventionally monitored by surface and IFT methods and conductivimetric measurements plotted against the surfactant concentration [27]. The surface tension method is also used to explain the micellization process of surfactant solutions as well as the distribution of molecules in presence of an additive, the surface activity and the micelle formation of ionic surfactants in combination with charged polymer and salt.

The surface tension behaviour of multi-components system can be obtained from the classical thermodynamic relationships for interfacial properties. The formulation adopted is that due to Gibbs and represented by [28,29]:

$$d\gamma = -\sum \Gamma_i \, d\mu_i \tag{10}$$

where γ, Γ_i and μ_i are the surface or the IFT, surface excess component and chemical potential of the component ($\mu_i = \mu_i^0 + \mathrm{RT} \ln a_i$; μ_i^0 is the standard chemical potential and a_i is the activity of i).

Using the expression of the chemical potential in Eq. (7), we obtain, for dilute solution ($a_i = C_i$):

$$d\gamma = -RT \sum \Gamma_i d \ln C_i \tag{11}$$

In a mixed multi-components system of constant composition, we have:

$$C_1 = KC_2 = KC_3 \tag{12}$$

Taking the log and differentiating, we have:

$$d\ln C_1 = d\ln C_2 = d\ln C_3 \tag{13}$$

Using this identity in Eq. (7), the Gibbs adsorption equation for a system containing three components (SDS, NaCl and XG) becomes:

$$d\gamma = -RT(\Gamma_{\mathrm{SDS}} + \Gamma_{\mathrm{NaCl}} + \Gamma_{\mathrm{XG}})d\ln C_1 \tag{14}$$

complete dissociation of NaCl, XG is assumed, and the dissociation of SDS produces DS^- and Na^+ of equal strength, below the CMC, hence:

$$\Gamma_{\mathrm{SDS}} = \Gamma_{\mathrm{DS^-}} + \Gamma_{\mathrm{Na^+}}, \tag{15}$$

This assumption is to consider positive adsorption, so, only the solute occupies the surface (the surface excess of pure solvent (here water) $\Gamma_{\mathrm{Solvent}} = 0$). Thus, the change in Γ, due to the change in concentration of any of the component can leads to the evaluation of the total excess:

$$\Gamma_{\mathrm{tot}} = \Gamma_{\mathrm{SDS}} + \Gamma_{\mathrm{NaCl}} + \Gamma_{\mathrm{XG}} \tag{16}$$

We consider that only the total IFT γ was obtained from the IFT measurements.

Fig. 4 represents the isoresponse plots for surface tension at varying xanthan gum and SDS concentrations, the n-Dodecan and NaCl are held at its zero level plot (n-Dodecan = 35% wt. and NaCl = 0.26% wt). The IFT values decrease with increasing SDS and XG concentrations (the minimum of surface tension (38.51 mN/m) are obtained for SDS = 1 (in coded values) which correspond to the concentration of SDS = 0.7% wt in natural values) and for XG = 0.8 in coded values (corresponding to 0.875%wt in natural values). In presence of electrolyte, here at varying SDS and at constant NaCl value in particular, the decreasing of surface tension can be explained by the addition of SDS (surfactant) which normally increases the IFT.

3.5. Influence of factors on the conductivity

Conductivity measurements was used extensively to study the interaction between polymers and surfactants in an aqueous solutions of these mixtures, they are very significant for the evaluation of electrostatic interactions in solution, especially when they involve charged substances (ionic surfactant, charged polymers and electrolyte). This method was used by Goddard [30] to investigate the effect of salt on the interaction between polymer (poly(ethylene oxide) and SDS, by Sovilj et al. [31] to investigate the influence of hydroxypropylmethyl cellulose–SDS interactions and by Nedjhioui et al. [19] to study the interaction between xanthan gum and SDS. The conductivity curves obtained from Eq. (7) and given in Fig. 5 which give the isoresponse plots at varying NaCl and tween concentrations values, and at constants (XG = 0.3% and SDS = 0.4%). The surface response curves show the effects of these varying concentrations while the two others were kept constant.

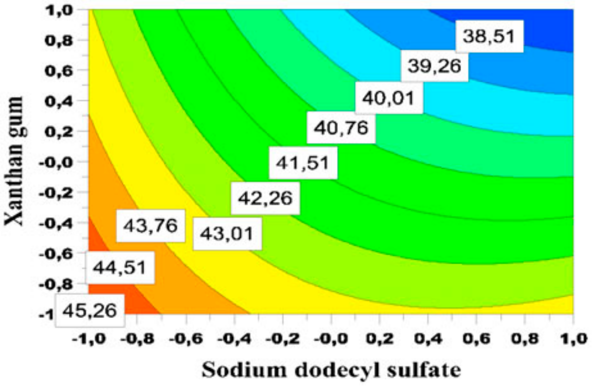

Fig. 4. Effect of SDS and XG concentrations on the IFT (mN/m): isoresponse plot (n-Dodecan = 0.3% wt. and NaCl = 0.26% wt.).

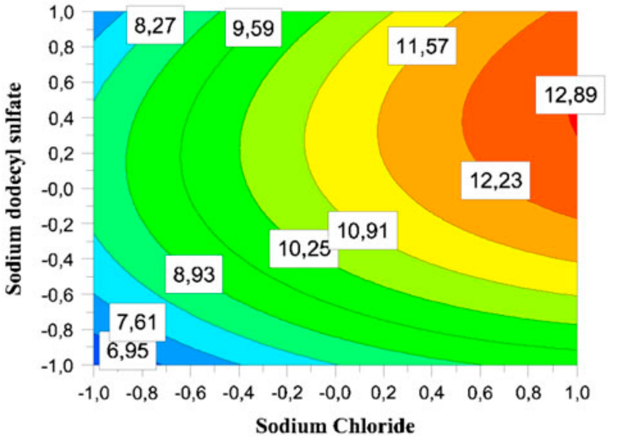

Fig. 5. Effect of SDS and NaCl concentrations on the conductivity (mS/cm): isoresponse plot (GX = 0.3% wt. and n-Dodecan = 35% wt.).

The specific conductivity of mixture containing the total sodium K_{Na}^{+} (the sum of free sodium in NaCl and in SDS ($C_{12}H_{25}SO_4Na$)), the free dodecyl sulphate ion $C_{12}H_{25}SO_4^-$ (DS^-), K_{DS^-}, free Cl^- containing in NaCl (K_{Cl^-}) and the conductivity of charged polymer, XG, (K_{XG}) and the conductivity of the non-ionic compound (n-Dodecan) is given in Eq. (7) [20,21]:

$$K = K_{Na^+} + K_{DS^-} + K_{Cl^-} + K_{XG} + K_{n-Dodecan} \quad (17)$$

In the present context, only the total conductivity of mixture *K* is obtained from the conductivity measurements.

Fig. 5 shows that the conductivity increases with increasing SDS and NaCl concentrations as expected while the two compounds are charged electrolytes. The maximum value of the conductivity (12.89 mS/cm) is obtained at NaCl = 1(in coded values), corresponding to the maximum concentration of NaCl = 0.5 w% and for SDS = 0.45 which correspond to 0.31 w%.

4. Conclusion

The combined effects of SDS, sodium chloride, xanthan gum and n-Dodecan concentrations on the physicochemical properties (shear rate, stress, IFT and conductivity) of aqueous solutions were investigated in the present work, with the aim to determine whether any interaction could occur using a statistical experimental design RSM. Previous study on the conductivity profiles of NaCl/Xanthan gum systems had shown the existence of interactions between polymer and surfactant and, the curves presented linearity as expected [16,17].

The plots representing the effects of the studied factors on the shear rate, the stress, the IFT and the conductivity had shown that these effects are much larger comparing with the conductometric plots, so, the effect of the n-dodecan, the SDS, the xanthan gum and the sodium chloride on response is well demonstrated using this statistical method and the isoresponse plots. The shear rate, the stress, the IFT and the conductivity,

The results shows that the shear rate values decrease with increasing XG and n-C_{12} concentrations and the maximum of shear rate (970.1 1/s) is obtained for n-C_{12} = 17.5% wt and XG = 0.01%wt . For the stress values, obtained results show the decreasing of this last with decreasing XG concentrations (the minimum is obtained for (1.6513 N/m^2) at SDS constant value and the stress values were kept practically constant when SDS concentrations changes for XG is kept constant.

The IFT results show decreasing of this property with increasing SDS and XG concentrations (the minimum of surface tension (38.51 mN/m) are obtained for SDS = 0.7% wt and for XG = 0.875%wt. These results assumed that the presence of electrolyte, here at varying SDS and at constant NaCl value in particular, the decreasing of surface tension can be explained by the addition of SDS (surfactant) in particular.

For the conductivity, results give composition of the optimum system (n-C_{12}, SDS, XG and NaCl) for each case. The results show increasing conductivities values with an increasing tween 80 concentrations and especially in presence of NaCl which is a strong electrolyte. The maximum value of the conductivity (12.89 mS/cm) is obtained at the concentration of NaCl = 0.5 w% and for SDS = 0.45 which correspond to 0.31 w%. This result shows the important role of the salt, this last is responsible of the electrostatic repulsions between charged molecules. The obtained results are foreseeable.

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