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Modeling Mucoadhesion by Use of Surface Energy Terms Obtained by the Lewis Acid-Lewis Base Approach: III. An Interaction Between Teflon and Carbopol

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INTRODUCTION

Rillosi and Buckton (1,2) have considered the interaction between Carbopol 934 and mucin in the presence of three fluids of different pH (model gastric, intestinal and saline). They have shown that some degree of correlation exists between the predicted free energy of interaction and measured mucoadhesive force.

The theory centres on the importance of acid-base (AB) interactions in surface and interfacial tensions. It is noted that interactions are dominated by the ability of compounds to either act as electron donors or electron acceptors (Lewis theory). Surfaces can be completely characterized by three parameters γ^{LW}, γ^{+} and γ^{-} representing the apolar (Lifshitz-van der Waals), electron acceptor and electron donor parameters, respectively. Quantitative information on these new surface energy parameters can be obtained by contact angle measurements with three adequate liquids (of which one must be apolar) on the solid of interest (see for example 1).

Once all the parameters are determined for two different materials 1 and 2, their interfacial tension γ_{12} is

$$\gamma_{12} = (\surd\gamma_1^{LW} - \gamma_2^{LW})^2 + 2(\surd\gamma_1^{+}\gamma_1^{-} + \surd\gamma_2^{+}\gamma_2^{-} - \surd\gamma_1^{+}\gamma_2^{-} - \gamma_1^{-}\gamma_2^{+}) \tag{1}$$

According to the Dupre' equation for interactions between particles or molecules 1 and 2 in a liquid 3

$$\Delta G_{132}^{TOT} = \gamma_{12} - \gamma_{13} - \gamma_{23} \tag{2}$$

$$\Delta G_{132}^{TOT} = \gamma_{12}^{LW} - \gamma_{12}^{LW} - \gamma_{23}^{LW} + 2[\surd\gamma_3^{+}(\surd\gamma_1^{+} + \surd\gamma_2^{-}\,\surd\gamma_3^{-} + \surd\gamma_3^{-}(\surd\gamma_1^{+}\,\surd\gamma_2^{+} - \surd\gamma_3^{+}) - \surd\gamma_1^{+}\gamma_2^{-} - \surd\gamma_1^{-}\gamma_2^{+}] \tag{3}$$

A negative value for the free energy of interaction will result in a net attraction between substance 1 and 2 immersed in a liquid 3.

The purpose of this work is to highlight an interaction between one of the probes that is used to assess surface energy (PTFE) and carbopol, which has resulted in erroneous surface energy parameters.

MATERIALS

Carbopol 934P was obtained from Goodrich Chemicals. Diiodomethane, glycerol, ethanol, were all of commercial purity grade. Isotonic saline, artificial gastric and intestinal fluid were prepared from distilled water according to USP XXII Ed. without adding any enzymes. The pH was 6.4 for saline, 7.5 for intestinal fluid and 1.2 for gastric fluid.

METHODS

Preparation of Polymers

Carbopol 934P was dispersed in distilled water (1% w/v) and magnetically stirred at room temperature up to complete polymer hydration (12 hours). Polymer films were prepared by dipping microscope cover glasses (24×32 mm) in the 1% dispersion and drying in air. The coated slides were used for contact angle experiments. To assess the surface energy and the Lifshitz van der Waals and electron donor/receptor contributions to the surface energy of the polymer, dispersions of Carbopol 934P in saline, gastric and intestinal fluid were prepared with different polymer concentrations, ranging from 0.5 to 6% (w/v). Surface tension measurements were performed on these solutions using a glass cover slide. The region of surface tension-concentration independence was found for all the samples. In this window the contact angle measurements were then obtained using solids of known surface energy. The surface energy and its component parts were then calculated by use of the surface tension and contact angles values between the polymer solution and two known solids (of which one was apolar i.e Teflon (PTFE) and one had known surface energy and polarity (polymethylmethacrylate, PMMA)). Surface energies were calculated at different pH values.

The surface energy of the PTFE and PMMA plates were checked by contact angle measurements with pure liquids, the surface tension of which was checked using clean glass plates.

RESULTS AND DISCUSSION

The surface energies for the carbopol, the artificial gastric and intestinal fluids and saline were calculated from the data in Tables 1 and 2 and are given in Table 3.

In comparison with the data published by Rillosi and Buckton (1,2) it can be seen that there are similarities for certain of the data especially considering the fact that the data here are for Carbopol 934P and that those reported previously were on Carbopol 934 (a less pure material) from a different supplier. However, vast differences between the results reported here and those obtained previously are seen for contact angles of carbopol on PTFE. This is despite the fact that the data reported here and that seen previously were both found to be reproducible.

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Table 1. Surface Tensions of Fluids and Contact Angles Measured on Plates for the Fluids and the Carbopol

	Surface tension (mN.m)	Cos θ (PTFE)	Cos θ (PMMA)
Mucin	47.1 ± 1.9	−0.51 ± 0.08	0.56 ± 0.05
Gastric fluid	75.9 ± 0.6	−0.28 ± 0.02	0.38 ± 0.04
Saline	74.5 ± 0.7	−0.38 ± 0.05	0.26 ± 0.04
Intestinal fluid	75.7 ± 0.2	−0.22 ± 0.04	0.34 ± 0.02

Note: At pH 7.5 the carbopol had to be used as a gel to reach concentration independence of surface tension.

Table 2. Surface Tensions and Contact Angles for Carbopol 943P at Different pH Values

	Surface tension (mN.m)	Cos θ (PTFE)	Cos θ (PMMA)
pH 1.2	46.0 ± 1.1	0.09 ± 0.02	0.55 ± 0.02
(3% solution)	(48)	(−0.55)	(0.41)
pH 6.4	46.0 ± 1.3	0.08 ± 0.03	0.58 ± 0.03
(2% solution)	(47)	(−0.55)	(0.42)
	Cos θ (water)	Cos θ (diiodomethane)	Cos θ (glycerol)
pH 7.5	0.86 ± 0.01	0.50 ± 0.01	0.71 ± 0.04
(gel on glass plate)	(0.86)	(0.49)	(0.92)

Note: Figures in brackets are data published by Rillosi and Buckton (1) for Carbopol 934.

Table 3. Derived Surface Energy Terms (all in mJ.m^{-2})

	γ^{TOT}	γ^{LW}	γ^{AB}	γ^{+}	γ^{-}
Mucin	46.2	6.9	39.3	49.2	7.8
Gastric fluid	75.9	40.4	35.5	5.8	54.7
Saline	74.5	28.8	45.7	6.9	75.8
Intestinal fluid	75.7	47.1	28.6	1.7	122.4
Carbopol 934P at pH 1.2	46.0	34.0	12.0	0.3	124.6
Carbopol 934 P at pH 6.4	46.0	28.7	17.9	0.1	400.0
Carbopol 934P at pH 7.5	32.0	28.6	3.4	1.1	2.7

The PTFE data presented in the current study were obtained only after a study of plate surface energy. The PTFE plate was (as always) initially checked by measuring contact angles of known pure liquids to verify the surface energy as being 18.5 mJ.m^{-2}. The plate was then used to measure contact angles on Carbopol 934P. The data (Table 2) were extremely reproducible, but were different from those which we had reported previously for Carpobol 934 (see comparison in Table 2) so the surface energy of the plate was once again checked. It was found that the surface energy of the plate had deviated such that when the plate was tested against fluids of known surface tension the results were not as expected, for example when the simulated gastric fluid was used the values were variable and in the region of -0.1, whereas the clean plate had given reproducible data of -0.28 (Table 1). The PTFE plate was cleaned by soaking in sodium hydroxide (0.2 M), then ethanol and then water. The surface energy of the PTFE returned to a value that was expected after the washing, however, further use of this plate resulted in measurements on Carbopol solutions which lacked any reproducibility.

A new PTFE plate was selected and its surface energy was verified. This was then used to measure the Carbopol solutions, with the plate being washed and having its surface energy checked (by contact angle measurements on pure liquids) after every single experiment. By use of this technique the surface energy remained constant and a reproducible value for the contact angle with Carbopol solutions was obtained (Tables 1 and 2). It is probable that the difficulties in obtaining consistent values for the Carbopol contact angle on PTFE is due to adsorption of the polymer to the plate. This adsorption process results in a plate which will generally yield uniform data, but which does not give the appropriate data as the plate has a surface energy different from that of PTFE. We believe that the difference between the data presented here and that presented previously (1,2) is due primarily to this adsorption behaviour, with the fact that this work has been carried out on a different (and more pure sample) being a secondary factor in the changes seen.

There are also some changes in observed surface energies of the buffer solution between those reported previously, which we had attributed to organic impurities in our earlier studies (2).

Having now obtained a different value for the contact angle on PTFE the derived surface energies of the Carbopol are significantly different from those we reported previously. These surface energy terms can be used to calculate the total free energy of adhesion between the Carpobol and mucin in the presence of the different fluids, yielding the following values: at pH 1.2 = −53.4 mJ.m^{-2}; at pH 6.4 = −126.35 mJ.m^{-2}; and at pH 7.5 = 90.6 mJ.m^{-2}.

CONCLUSIONS

The tendency for Carbopol to adsorb to PTFE plates (and the fact that this could also occur when using other probe plates) makes it necessary to use very great care when measuring surface energies to ensure that the nature of the probe plate is unchanging. The presence of reproducibility in the experimental data does not equate to measuring the correct contact angle value.

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