Surface energies of epoxy resin Epon 1001F at varying temperatures by use of the pendent drop technique

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SURFACE ENERGIES OF EPOXY RESIN EPON 1001F AT VARYING TEMPERATURES BY USE OF THE PENDENT DROP TECHNIQUE

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ABSTRACT

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SURFACE ENERGIES OF EPOXY RESIN EPOX 1001F AT VARYING TEMPERATURES BY USE OF THE PENDENT DROP TECHNIQUE

Advisor: Professor Kofi B. Bota

Thesis dated December 1984

The determination of surface energies of the epoxy resin Epon 1001F by use of the pendent drop technique is discussed.

Surface energies of Epon 1001F measured by this technique at 90, 100, and 120° were found to be 41.74, 40.80, and 38.59 dynes/cm, respectively, under a nitrogen atmosphere assuming the density of pure Epon 1001F was the same as that of pure Epon 828 at the same temperatures.
ACKNOWLEDGEMENTS

I wish to thank Dr. Kofi B. Bota, my research advisor, for his assistance and his continual confidence in my ability to complete this work. Great appreciation is given to Dr. Frank Weaver for his encouraging help to complete this work. I wish to thank Dr. Frank Cummings for his encouraging help in putting this paper together. I would like to give credit to Everett White and Fred Okoh for their friendship throughout the course of this work.
DEDICATION

To all those who in one way or another stood beside me when everything fell apart and helped me put it back together: my parents, my sisters, my brothers, my son, my family. To my wife who has braved it beside me through good and bad times, but who was always there when I needed her. To the Gadsden family, their support made it all happen. I would like to thank the Gill family for the help given me when I needed help. And to all those who in one way or another stood beside me all the way.
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INTRODUCTION

The surface energy of solid polymers is a very important quantity, since it permits one to characterize the adhesion and adsorption ability of polymeric surfaces. It is also of theoretical importance because a number of polymeric materials depend on the structure and properties of the surface layers. Surface energy (ergs/cm²) is expressed as the work in ergs required to increase the surface area by 1 cm, at constant temperature, and is numerically identical with surface tension (dynes/cm²). Surface tension is the force that pulls the surface of a liquid inward and resists the expansion in surface area. Liquid droplets assume a spherical shape as this minimizes their surface area.

Methods of direct determination of surface tension can not be used for solid polymers because polymers have a distribution of relaxation times and various mechanical losses. Currently there is no concrete method to determine the surface energies of solid polymers. The difficulty in doing so can be explained by the fact that fluidity is very poor or absent and, therefore, the direct determination of these surface energies is not easy.

Surface Tension and Temperature

The temperature of a liquid in equilibrium with its own vapor eventually reaches the critical point of the substance upon heating if no complications such as decomposition take place. At the critical temperature there is no difference between liquid and vapor and no surface
tension can exist. The general trend of the relationship between surface tension and temperature is determined by this. The value of the surface energy is found to be higher the further away the temperature of an experiment is from the critical temperature. Within a range of temperatures, the surface tension may be constant or even increase on heating when the molecular composition of a liquid changes with temperature. Many liquids have surface energy values which monotonically decrease with increasing temperature.  

Methods of Measuring Surface Tension

There are several methods that can be used to determine and study surface energies. One finds that these methods differ greatly in their accuracy, ease of temperature control, the volume of liquid needed, and the effort required to obtain each measurement.

Before choosing a method to study the surface energies of a system, one must take into consideration the peculiarities of the system to be measured. Some of these methods are static, enabling the experimenter to study the change of surface energies with time. Others are truly dynamic, enabling the determination of surface energies of freshly formed interfaces. In between are semi-static methods, which require detachment of the liquid from a solid supporting surface sufficiently slowly that the value obtained approaches that of the surface at equilibrium.

In some methods the contact angle between the liquid and a solid surface has to be known, while others are found to be independent of the contact angle. Some methods are absolute and others require calibration. Some are not well suited to the measurement of very low surface energies.
We provide in the following section a brief description of some of these techniques.5

The capillary rise method is generally considered to be the most accurate of all methods, partly due to the close control of the experimental variables.6 However, corrections have to be made to account for the shape of the meniscus at the interface.5,7,8 The major weakness of this method is the assumption that the liquid perfectly wets the capillary tube.

The drop weight method5 is fairly accurate and perhaps the most convenient laboratory method for measuring surface energy of a liquid-air or liquid-liquid interface. The method does not depend upon the contact angle. It is a reliable technique for determining very low interfacial tensions at very low density differences of the two phases involved.

The ring method6 is a method which involves the determination of the force to detach a ring or loop of wire from the surface of a liquid. It is a very popular method for determining the surface energy.

The maximum bubble pressure method6 is independent of the contact angle of the liquid on the capillary tube from which the bubbles are liberated. It is absolute and does not require any calibration, except for the correction factors that must be applied.5 It is not a widely used method.

The pendent-drop technique has a number of outstanding advantages over other methods. The use of an inert environment suppresses any oxidation of the drop surface. An accurate study of changes in surface composition with time can also be made by use of the pendent-drop technique.
The method we choose to determine the surface energies of Epon 1001F was the pendent-drop technique. With this technique very accurate results can be obtained provided there is a minimal amount of external vibration. It is a technique that requires only a small volume of liquid; furthermore precise temperature control can be attained. It is also exact and does not require correction nor calibration.

**Epoxy Resins**

The general structure of epoxy resin Epon 1001F and the functionalities responsible for epoxy properties are shown in Fig. 1. Epoxy resins are polyethers and are synthesized by a two-step polymerization sequence in which the first step is based on the step-growth polymerization reaction with a bifunctional or polyfunctional nucleophile.

A large excess of an epoxide monomer is used to synthesize low molecular weight, linear polyethers with reactive epoxide end groups in a first-step. Epichlorohydrin is the most widely used epoxide monomer. The structures of bisphenol a-epichlorohydrin resins, the components of Epon 1001F, are shown in Fig. 2.

Because of the limited favorable physical properties of the very low molecular weight polymers formed in the first-stage polymerization reaction, epoxy resins must be further reacted, or cured, to form high molecular weight macromolecules in a subsequent reaction. These second-stage reactions yield crosslinked or network polymers.

Epoxy resins are cured by many types of materials, including polyamines, polyamides, poly-sulfides, and urea, through coupling or
Fig. 1. Functional groups responsible for epoxy properties.

Fig. 2. Structures of bisphenol a-epichlorohydrin.
condensation reactions. The amines are the most important class of curing agents for reactions involving epoxy end groups. When reacted with amines, ring-opening of the epoxide ring occurs to give β-hydroxy-amino linkage:9

\[
\begin{align*}
\text{-CH}_2\text{CH}_2\text{RNH} & \quad \overset{0}{\longrightarrow} \quad \text{OH} \\
\text{CH}_2\text{CH}_2\text{NHR} & \quad \text{CH}_2\text{CH}_2\text{NHR}
\end{align*}
\]

Epoxy resins are mainly used as surface-coating materials, which combine toughness, flexibility, adhesion, and chemical resistance to a nearly unparalleled degree. They can also be used in both molding and laminating techniques to make glass fiber-reinforced articles with better mechanical strength, chemical resistance, and electrical insulating properties than those obtained with unsaturated polyesters. The liquid resins are often used although the hot-melt solids have some application. Industrial flooring, adhesives, solder foams, highway surfacing and patching materials, and stabilizers for vinyl resins are some of the other important uses of epoxy resins.9
EXPERIMENTAL

With minor changes the experimental apparatus was set up as described by Patterson and Ross\textsuperscript{10} to determine surface energies of the resin Epon 1001F using the pendent-drop technique. The alignment of the photographic system used here was that described by Bagnall.\textsuperscript{11}

The resin Epon 1001F sample was supplied by the Miller-Stephenson Chemical Company. The benzene was supplied by the Fisher Scientific Company with a purity of 99 mole%. Hexane was supplied by the J. T. Baker Chemical Company.

**Pendent-Drop Apparatus**

A schematic drawing of the apparatus used in this study is shown in Fig. 3.

The optical and camera systems were set up on two independent vibration free tables, the optical system on a 1000 lb granite tabletop, which is part of the Ealing vibration-isolation stand, and the camera system on an optical bench set upon 1000 lb of concrete blocks, which in turn sit on some auto tire inner tubes (Fig. 3). The two table systems were set up in order to eliminate vibration, a major impediment to obtaining sharp drop images.

The optical system consists of a light source whose arc can be adjusted with respect to the optical bench. A plano-convex lens is put in position to collimate the light beam. A green filter positioned in
Fig. 3. Schematic of experimental apparatus for pendent-drop photography.
the light path is restful on the eyes, particularly when studying changes in drop shape over long periods.

The pendent-drop cell is placed after the filter on a mount in-between the light source and the camera. The camera uses a 75 mm lens and a (4 x 5 inch) Polaroid film back. This set-up gives a magnification of 12X.

A separately mounted shutter, independent of the two vibration-free optical and camera systems is placed directly in front of the camera lens in-between the camera and the pendent-drop cell. Well defined negatives were achieved by presetting the shutter at shutter speeds of 0.25 sec.

This set up produces a photograph of the drop using rays of the light that are essentially parallel to the optical axis. Drops were formed from syringes made from disposable capillary pipets (heavy wall glass) from Van-Lab. Plungers for these syringes are made from glass-rods. In order to make sure that the syringe tip is upright and not tilted to an angle, a plumb line is set up at the back of the camera. This provides for parallel alignment of the syringe tip.

A schematic drawing of the pendent-drop cell used is shown in Fig. 4. It is a high temperature aluminum block cell, with an inlet and outlet connection to readily deliver and remove nitrogen, the inert gas used in this experiment to prevent air oxidation to the drop. The cell temperature is controlled by six 50 watt cartridge heaters that are powered by a proportional controller. A platinum resistance thermometer was utilized for temperature measurements. The temperature stability of the aluminum block is within 0.1° over our experimental temperature range.
A - optically flat windows
B - cavities for cartridge heaters
C - cavity for syringe and needle
D - gas inlet
E - thermocouple well
F - cell cover with opening

Fig. 4. Schematic of high temperature aluminum block cell.
Experimental Problems of the Pendent-Drop Method

Vibration was one of the major difficulties encountered. The experiments were performed on the third floor of a three story building. A major city street and a rapid transit subway line runs through the campus. Wind and students moving up and down the hallway during class periods all were sources of vibration.

Oxidation, another problem when the resin was exposed to the atmosphere upon heating, was largely controlled by use of an inert environment whenever taking photographs of the pendent-drop.

Drop Formation

The barrel of the syringe was filled with the Epon 1001F. The plunger (a glass stirring rod cut to size) was placed in position in the barrel and pushed so as to form a resin seal on the syringe. The cell was flushed with the inert nitorgen at constant flow through the cell via the inlet and outlet tubes. The syringe was introduced into the cell with a rubber stopper (single hole) to fit the opening on the cell top. The drop was formed by applying slight pressure to the plunger and was left hanging from the tip of the syringe.

Photography

All the photographs were taken at 0.25 sec shutter speeds. The exposed film was developed in the Polaroid portable negatives clearing tank for about 10 min and then rinsed in cold running water for about 20 min. The
were then hung to dry. All of the operations were carried out at room temperature. The developed photographs were treated with Polaroid print coater.

**Measurement**

The surface energy measurements were done under dry nitrogen atmosphere, in order to suppress oxidation of drop surfaces. The experiments were also done at room temperature and pressure. An inert gas was used in preference to a vacuum because it is easier to displace oxygen by another gas than to remove it by pumping it out.

The surface energy measurements of benzene, hexane and water were done in a water-thermostatted Helma glass cell as shown in Fig. 5. Their densities were determined by the buoyancy method. The density of Epon 828 was determined by use of a pycnometer and a dilatometer.

Fig. 6 shows a photograph of a pendent-drop and a steel ball. After the pendent-drops were photographed and negatives processed, the drop dimensions $d_e$ and $d_s$ were measured from the photographic negatives using a Mann Linear comparator interfaced with a Bausch and Lomb Accurite digital readout.

The two drop dimensions $d_e$ (the maximum drop diameter) and $d_s$ (the drop diameter at a distance $d_e$ above the apex) are defined in Fig. 7.

At least five to six photographs were taken at each temperature and the best four were used for surface energy calculations.
A - cavity for syringe and needle
C - water inlet
E - plastic stopper
B - water pocket and cavity
D - water outlet
F - optically flat windows
  (minimal refraction)

Fig. 5. Schematic of water-thermostatted Helma glass cell.
Fig. 6. Photograph of a pendent-drop and a steel ball.
$R_1 =$ radius of curvature in the plane of the paper (not shown in the figure)

d$_e =$ maximum diameter

d$_s =$ diameter of drop at distance $d_e$ from apex

$$S = \frac{d_e}{d_s}$$

Fig. 7. Pendent-drop profile and drop dimensions.
RESULTS AND DISCUSSION

The equation for the profile of a pendent-drop can be shown to be

\[ \frac{2}{b} + \Delta \rho g z = \frac{1}{R_1} + \frac{1}{R_2} \]  

where

\[ \gamma = \text{surface energy} \]

\[ b = \text{radius of curvature at the apex (where } x = z = 0) \]

\[ x \text{ and } z = \text{the coordinates of any point on the drop profile} \]

\[ R_1 \text{ and } R_2 = \text{the principal radii of curvature at any point on the profile (Fig. 7)} \]

\[ \Delta \rho = \text{density difference between liquid phase (melted resin) and gas phase (nitrogen)} \]

\[ g = \text{acceleration due to gravity (cm/sec}^2) \]

The surface energy \( \gamma \) was calculated using eqn. 2.11,12

\[ \gamma = \frac{\Delta \rho g d_e^2}{H} \]  

where

\[ d_e = \text{maximum drop diameter} \]

\[ 1/H = \text{correction factor for pendent-drop shape from published tables of } S \text{ versus } 1/H.6 \]
With some mathematical manipulation eqn. 2 can be derived from eqn. 1.\textsuperscript{11} The average values and standard deviations of the measurements of $d_e$ and $d_s$ were calculated and used to find $S$ and from this $1/H$.

Epon 1001F is a solid at room temperature. It softens or melts around $65^\circ$. The density of pure Epon 1001F was assumed to be the same as the density of pure Epon 828 at the temperatures being studied. This assumption was made because both resins have a common repeating unit called the 'monomeric' unit as shown in Fig. 2 and also at the time the experiments were carried out, means of calculating densities of solids were unavailable to us. When $n$ is small, polymers tend to be liquids (Epon resin 828) and when $n$ is large, polymers tend to be solids (Epon resin 1001). The densities of pure Epon 828 at 90, 100 and 120 $^\circ$ are reported in Table 1.

Table 1. Densities of Pure Epon 828.*

<table>
<thead>
<tr>
<th>Temperature (C)</th>
<th>Density (g/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>1.1170</td>
</tr>
<tr>
<td>100</td>
<td>1.1096</td>
</tr>
<tr>
<td>120</td>
<td>1.0964</td>
</tr>
<tr>
<td>140</td>
<td>1.0833</td>
</tr>
</tbody>
</table>

*Measured by Dr. Frank Weaver and Mr. Everett White.

The density difference $\Delta \rho$ between the liquid phase (drop) and surrounding gas phase (nitrogen gas) was determined by taking the arithmetic dif-


ference between the liquid density and gas density. The densities of Epon 1001F were determined as previously discussed and the densities of nitrogen gas at the experimental temperatures were obtained from tables.

Several tests were made of the accuracy of the photographic pendent-drop apparatus used. Photographs of a steel ball were taken and the average diameter was found to be accurate to ± 0.1%. The average magnification factor from six negatives expressed as the measured ball diameter from the negative divided by the actual ball diameter 3.175 mm, was 12.124 ± 0.009 (precision = 0.080%). These experiments were done at room temperature.

At 90 °, the mean magnification factor (the average magnification over the series of photographs taken at this temperature) was found to be 12.030 ± 0.012 (0.101%), and at 100 ° the mean magnification factor was found to be 12.01 ± 0.015 (0.122%) using a steel ball. The photographs were all double exposed in order to get both the pendent-drop and steel ball on the same photograph as shown in Fig. 6.

The magnification factors differ with temperature due to some unknown experimental factor. Possible sources of this were optical system distortions caused by the projection lens, non-alignment of various components of the system, or imperfections in cell windows.

The consistency of the magnification factor over most of the negatives indicates the kind of accuracy we were getting. Our overall mean was found to be 12.017 ± 0.022 which is in good agreement with Bulter and Bloom's recommendation of a magnification factor precise to 0.02%. We also found that the standard deviation values (±) for the magnification were much smaller than those for the surface energies in our experiments.
The surface energies of benzene, cyclohexane, hexane and water were measured at 20° and benzene at 30° as checks on our system. The values measured for these systems are examined in Table 2 and are found to compare within 0.06 to 1.8% of literature values. Desired accuracy was 0.5%. We note that all of our calculated surface energies are systematically lower than the literature values, and that the literature values fall within or just above the experimental upper limit.

Table 2. Surface Energies of Model Liquids at 20 and 30°.

<table>
<thead>
<tr>
<th>System (T/°C)</th>
<th>Surface Energies/dyne cm⁻¹</th>
<th>This study</th>
<th>Literature</th>
<th>% deviationa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene (20)</td>
<td>dₑ = 2.0058</td>
<td>28.86 ± 0.67</td>
<td>28.88</td>
<td>0.06</td>
</tr>
<tr>
<td>Hexane (20)</td>
<td>dₑ = 2.243</td>
<td>18.22 ± 0.15</td>
<td>18.41</td>
<td>1.03</td>
</tr>
<tr>
<td>Water (20)b</td>
<td></td>
<td>72.58 ± 0.82</td>
<td>72.88</td>
<td>0.41</td>
</tr>
<tr>
<td>Cyclohexane (20)b</td>
<td></td>
<td>24.52 ± 0.37</td>
<td>24.98</td>
<td>1.80</td>
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</table>

a100 x (SELIT - SEEXP)/SELIT

bMeasured by Dr. Frank Weaver and Mr. Everett White.
The surface energies of epoxy resin Epon 1001F were determined at 90, 100 and 120°. The average values at these temperatures were found to be 41.74, 40.80 and 38.59 dynes/cm, respectively. A summary of surface energies of epoxy resin Epon 1001F determined in this study are reported in Table 3.

Table 3. Calculated Surface Energies of Pure Epon 1001F at 90, 100, and 120°.

<table>
<thead>
<tr>
<th>Exposure #</th>
<th>ρ</th>
<th>MF</th>
<th>d_e/cm</th>
<th>d_s/cm</th>
<th>Surface Energies/dynes/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>T = 90</td>
<td>1.170</td>
<td>12.024</td>
<td>2.5596</td>
<td>2.0269</td>
<td>41.59</td>
</tr>
<tr>
<td>MS1-7-1</td>
<td></td>
<td>12.021</td>
<td>2.479</td>
<td>1.922</td>
<td>41.25</td>
</tr>
<tr>
<td>MS1-7-2</td>
<td></td>
<td>12.048</td>
<td>2.464</td>
<td>1.8872</td>
<td>42.08</td>
</tr>
<tr>
<td>MS1-7-3</td>
<td></td>
<td>12.027</td>
<td>2.2887</td>
<td>1.6581</td>
<td>42.03</td>
</tr>
<tr>
<td>MS1-7-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>41.74±0.33</td>
</tr>
<tr>
<td>T = 100</td>
<td>1.1096</td>
<td>11.986</td>
<td>2.4764</td>
<td>1.9214</td>
<td>40.86</td>
</tr>
<tr>
<td>MS1-6-1</td>
<td></td>
<td>12.005</td>
<td>2.633</td>
<td>2.135</td>
<td>41.12</td>
</tr>
<tr>
<td>MS1-6-2</td>
<td></td>
<td>12.017</td>
<td>2.5326</td>
<td>1.9967</td>
<td>40.99</td>
</tr>
<tr>
<td>MS1-6-3</td>
<td></td>
<td>12.017</td>
<td>2.3908</td>
<td>1.8186</td>
<td>40.24</td>
</tr>
<tr>
<td>MS1-6-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>40.80±0.33</td>
</tr>
<tr>
<td>T = 120</td>
<td>1.0964</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS1-8-1</td>
<td>c</td>
<td></td>
<td></td>
<td></td>
<td>38.81</td>
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<td>39.28</td>
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<tr>
<td>MS1-8-3</td>
<td>c</td>
<td></td>
<td></td>
<td></td>
<td>38.26</td>
</tr>
<tr>
<td>MS1-8-4</td>
<td>c</td>
<td></td>
<td></td>
<td></td>
<td>38.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>38.59±0.49</td>
</tr>
</tbody>
</table>

Assumed densities of Epon 1001F from Table 2.
MF=Magnification factor
Measurement not used in this study
Fig. 8. Surface energy versus temperature for Epon 1001F.
Far below the critical temperature, the surface energy of most small-molecule liquids varies nearly linearly with temperature as found also for polymer fluids. The observed temperature coefficients for polymer fluids are generally smaller than those of nonpolymeric liquids. The effect of temperature on surface energy of Epon 1001F is shown in Fig. 8. Surface energy was found to decrease with temperature as expected. We observed good linear behavior of surface energy as a function of temperature. The temperature coefficient, was found to be \(-0.114\) dynes/cm \(\degree C\). It was found to be in line with a value of \(-0.1\) dynes/cm \(\degree C\) reported by Dearlove for a comparable bisphenol a-epichlorohydrin epoxy resin and with values of \(-0.05\) to \(0.08\) reported by Gaines for polymer surfaces.

During the course of our research, we encountered some problems: (1) bubbles in the pendent-drop, and (2) short drop age (the length of time a drop stays adhered to the syringe tip from time of formation).

Epon 1001F, a solid at room temperature, has some gas(es), volatile solvents, or surface active impurity(ies) which slowly diffuse to the interface (liquid-gas) after a period of time upon heating the polymer. Bubbles are formed as a result of this. The motion of the bubbles in the melted resin cause an unwanted motion of the pendent-drop during the photographing process and was evident in the quality of the photographs. The photographs either were blurred or showed no well defined edges for the drop. Some showed no symmetrical shape of the drop. All this caused problems when it came to measuring the drop dimensions off the negatives. The measurements of the same drop dimension were inconsistent due to the fuzzy edges. Modifications in loading the syringe barrel were made in an attempt to remove bubbles from the resin before drops were formed.
The resin was first melted, using mineral oil as a median for heat transfer, and then poured into the barrel. This resulted in a slight reduction in bubbles. We never did find a way of removing bubbles completely from the melted resin.

Melting the resin first added the problem of resin color change. We attributed the color change to oxidation of the epoxy resin since the melting process was done with the resin exposed to the atmosphere. The reason for melting the resin in a non-inert environment was that there were no facilities available to us at the time to carry out the process in an inert environment. The color change could also have been due to surface active impurities diffusing to the surface and reacting with the resin surface upon heating. Attempts by Dr. Weaver to trap volatile components of Epon 828 and identify them by spectroscopy were unsuccessful. We never attempted to trap the volatile components of Epon 1001F due to the unsuccessful attempt with Epon 828.

The surface energies of Epon 1001F were determined with air bubbles present at all three temperatures. The values of surface energy were affected and could be seen in the higher uncertainty values that we calculated at 120°. However it may be noted that a comparison of the precision values of our model systems to those of Epon 1001F show no apparent differences in the two sets of values.

The short drop age problem was one that could be linked to the bubble problem. Because of the motion of the pendent-drop caused by the bubbles trying to escape, the drops would not adhere to the tip of the syringe for too long. The average drop age for our experiments was 5 min. Due to this
problem we were unable to study the pendent-drops for long periods of time, which would have allowed us to determine whether or not the drops reached hydrostatic equilibrium which requires drop ages of at least 10 min.¹⁶
CONCLUSION

A pendent-drop apparatus was set up, calibrated, tested and surface energies of epoxy resin Epon 1001F were measured at 90, 100 and 120°. The surface energies determined were 41.74 ± 0.33, 40.80 ± 0.33 and 38.59 ± 0.49, respectively.

A possible extension of this work would be to find a way of containing the bubble problem and then continuing on to determine whether or not the drops reach hydrodynamic equilibrium and also follow the rate of approach to hydrodynamic equilibrium. Another extension would be to determine the surface energies of Epon 1001F at higher temperatures.
REFERENCES

1. Lipatov, Y.; Feinerman, A. Advances in Colloid and Interphase Science 1979, 11, 195.