GEORGIA INSTITUTE OF TECHNOLOGY
ENG 4793 Composite Materials and Processes

Spring 2002

MEGA Problem Set
The due date for each problem will be assigned in class.

Permeability:

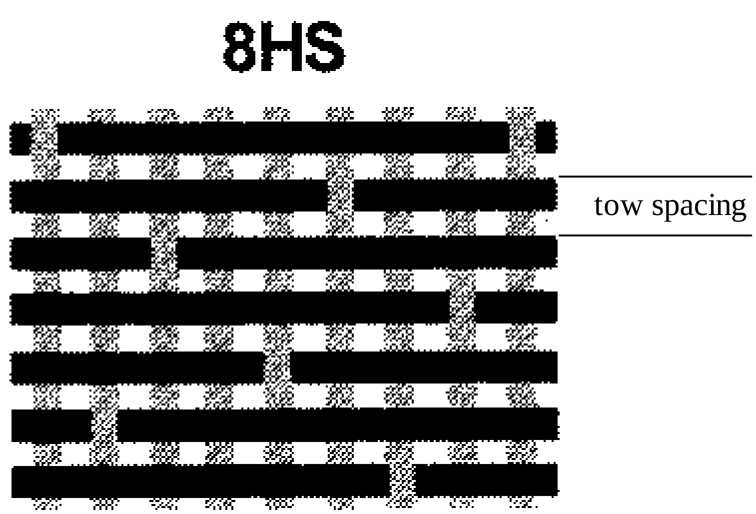
For advanced carbon fiber composites a satin weave is often used. In such fabrics the permeabilities of the fabric and tows are different. Assume the tow has a rectangular cross-section with a fiber volume fraction of 0.85. Each tow contains 12,000 filaments with diameters of 8 microns. The width of the tow is 6 times greater than the thickness of the tow. Since it is a satin weave the fibers are aligned almost perfectly in the plane. The fabric is an 8 HS (harness satin, see figure below). The tow spacing (see figure below) is 3 mm. Assume the epoxy prepolymer is pressed into the fabric from above using a pressure of 100 psi. The viscosity of the epoxy is 1 Poise. Assume the Kozeny constant for both the tow and fabric is 18.

a) Calculate the permeabilty of one tow in mm^2.

b) Calculate the time for the epoxy to permeate one tow in seconds.

c) Calculate the permeability of the fabric in mm^2.
(Determine the hydraulic radius of the tow. Assume for this calculation that the tows are impermeable.)

d) Calculate the time for the epoxy to permeate the fabric in seconds. Discuss in comparison to the tows.



Fiber Compression:

A composite consisting of glass fibers ($r = 10\mu m$) is being compressed between flat plates. The initial volume fraction is 35%. The fibers will take up, at best, a square array. The modulus of the fibers is 10.5×10^6 psi. What is the load the fibers will carry when the composite is at its final volume fraction of 50%? Assume $\beta = 300$.

Compression Molding:

In the example presented in class, the rate of time change of the volume fraction was prescribed. In many compression processes, the pressure is kept constant (prescribed). For the same material parameters as the class example, but with a constant applied pressure of 10 kPa, determine the final fiber volume fraction and the time that it will take to get to that fully wet condition. At this point, what are the contributions of the fiber network and of the resin to the overall pressure? (Solve on the computer.)

Parameters:

Viscosity: 0.3 kPa•s (typical of polypropylene)
Carbon fiber modulus: 234 GPa
V_o (initial volume fraction): 0.55
V_a (available volume fraction): 0.85
k (Kozeny coefficient): 0.7 (axial flow)
r_f (carbon fiber radius): 4 microns
a (length of fiber we're trying to fill with resin): 0.01m
beta (fiber arch ratio): 350

Wetting:

Given the following information:

γ (epoxy) = 50 dynes/cm
γ (Hifax) (a polypropylene) = 32 dynes/cm
γ (water) = 73 dynes/cm
γ (clean glass fibers) = 500 dynes/cm
γ (dirty glass fibers) = 10 dynes/cm
γ (Lexan) (a polycarbonate) = 21 dynes/cm

Answer the following questions, with quantitative results:

a) Will water wet Hifax?
b) Will epoxy stick to clean glass fibers?
c) Will epoxy stick to dirty glass fibers?

d) Will Lexan and Hifax stick together?

Prepregging with wetting:

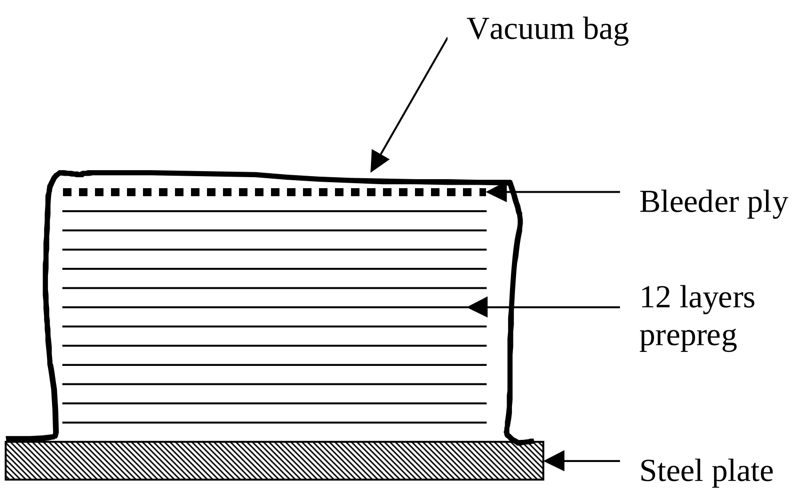
Given a resin with a surface tension, $\gamma = 30 \times 10^{-3}$ N/m, a viscosity, $\mu = 100$ N s/m^2, wetting a fiber network composed of fibers with a radius of 10 μm, surface tension, $\gamma = 500 \times 10^{-3}$ N/m, volume fraction, $v_f = 64\%$, and fiber network thickness = 2 mm (you can assume that this is the superficial distance) under a pressure of 8×10^5 Pa (for the resin). The pore size, δ, can be assumed to be 5 μm and the Kozeny constant to be 0.7. Assume that the resin only infiltrates the fibers from one side (the top).

a) How long does it take to infiltrate the fibers with resin?

b) How much effect does wetting have? When will its effect be significant?

Conduction Heat Transfer

What is the thermal conductivity through the thickness direction (up/down in the figure) of the following lay-up?



The lay-up consists of a steel plate, t = 25 mm; 12 layers of 60/40 by vol% glass fiber/epoxy prepreg, the thickness of each layer is 125 μm; the bleeder ply has a porosity of 60%, t = 0.15 mm; and the vacuum bag, t = 0.13 mm. You may assume that the resin has infiltrated the fibers and bleeder ply completely.

Thermal conductivity of resin = 0.1675 W/m-K
Thermal conductivity of bleeder ply = 1 W/m-K
Thermal conductivity of steel = 45 W/m-K
Thermal conductivity of glass fiber = 1.3 W/m-K
Thermal conductivity of vacuum bag = 0.243W/m-K

Radiation Heat Transfer

a) If an Azdel material (glass and polypropylene) at room temperature (20 C) is being heated in a radiant heater (T = 1000 C), what is the initial heat flux and heat transfer coefficient?

b) What is the heat flux and heat transfer coefficient when the part is at its processing temperature of 210 C? Comment on the difference in the results from a) and b) and its effect on processing.

Assume the radiant heaters are very efficient with $\varepsilon = 0.95$, and the Azdel has $\varepsilon = 0.85$. Assume the view factor F= 1 and $\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$

Reaction Kinetics - 1

A 20 mg sample of PR 500 is cured at 220°C in a DSC. Assume a heat of reaction of 218 J/g and an initial degree of cure, α, = 0. Use the kinetic and viscosity expressions on the attached pages.

Determine (solve on computer):

1) The time in minutes to reach the maximum rate of heat generation and compare with the attached pages.
2) The maximum rate of heat generation in microWatts (also compare with attached pages)
3) The degree of cure at this maximum
4) The viscosity in cP at this maximum

Reaction Kinetics -2

For the same sample in Reaction Kinetics - 1 predict the temperature in °C where the maximum rate of heat generation occurs when the sample is heated at a constant rate of 10 °C per minute starting at 30 °C. (Solve on computer.)

Filament Winding:

Consider the filament winding of a 18 inch diameter part using a continuous carbon fiber reinforcement and an epoxy resin. Determine how fast the fibers will move toward the mandrel. What does this mean in terms of winding speed?

You may assume that the fibers are in contact with 180 degrees of the mandrel for your analysis. The fibers have a tension of 5 lbs. on them. The fiber bundle is 0.5 inches wide and 0.01 inches thick. The fiber diameter is 8 microns, the volume fraction of fibers is 64%, and the Kozeny constant is approximately 0.7 for the system. The resin viscosity is 8 Poise.

Pultrusion:

You are pultruding a thermoset matrix composite prepreg. The die has a taper of 10 degrees and a taper length of 3 inches and a constant width of 0.25 inches. After the taper, the die has a length of 6 inches, with a constant width of 0.25 inches and a thickness of 0.05 inches. The fibers are glass with a modulus of 10.5×10^6 psi, and an available volume fraction of 0.785, and initial volume fraction of 0.5, a final volume fraction of 0.6, a diameter of 20 microns, and a $\beta = 220$. The resin has a viscosity of 3 Poise. The pulling velocity is 10 mm/s.

a) Determine the pulling force for the tapered section.

Hint: Try fist using "average" values. Ignore wetting. Assume a Kozeny constant of approximately 1 for axial flow.

b) After using the average values, discuss how the "real" answer will differ.

Autohesion

A new, thermoplastic matrix - glass fiber composite is processed by a compression technique that brings the layers of the prepreg material into contact for 2 seconds at 175°C. If the T_g of the material is 150°C, is the processing time long enough to assure a degree of autohesion of 1? Discuss your answer in terms of the processing technique.

$$\log a_T = [-17.44(T - T_g)]/[51.6 + (T - T_g)]$$

$$D_{AU} = 0.2*(t/a_T)^{0.25}$$

Kinetics + Viscosity
PR500 Case Study

DSC

<Name>
MachPR500-130
<Date>
93/03/10 16:27

<Sample>
PR500-I130
6.279 mg
(6.279 mg)
<Reference>
nitrogen
0.000 mg

<Comment>
Isothermal 130
<Sampling>
5.0 sec

<Temp.program[C] [C/min] [min]>
1* 20.0- 130.0 100.00 500.00
<Gas>
0.0 ml/min
0.0 ml/min

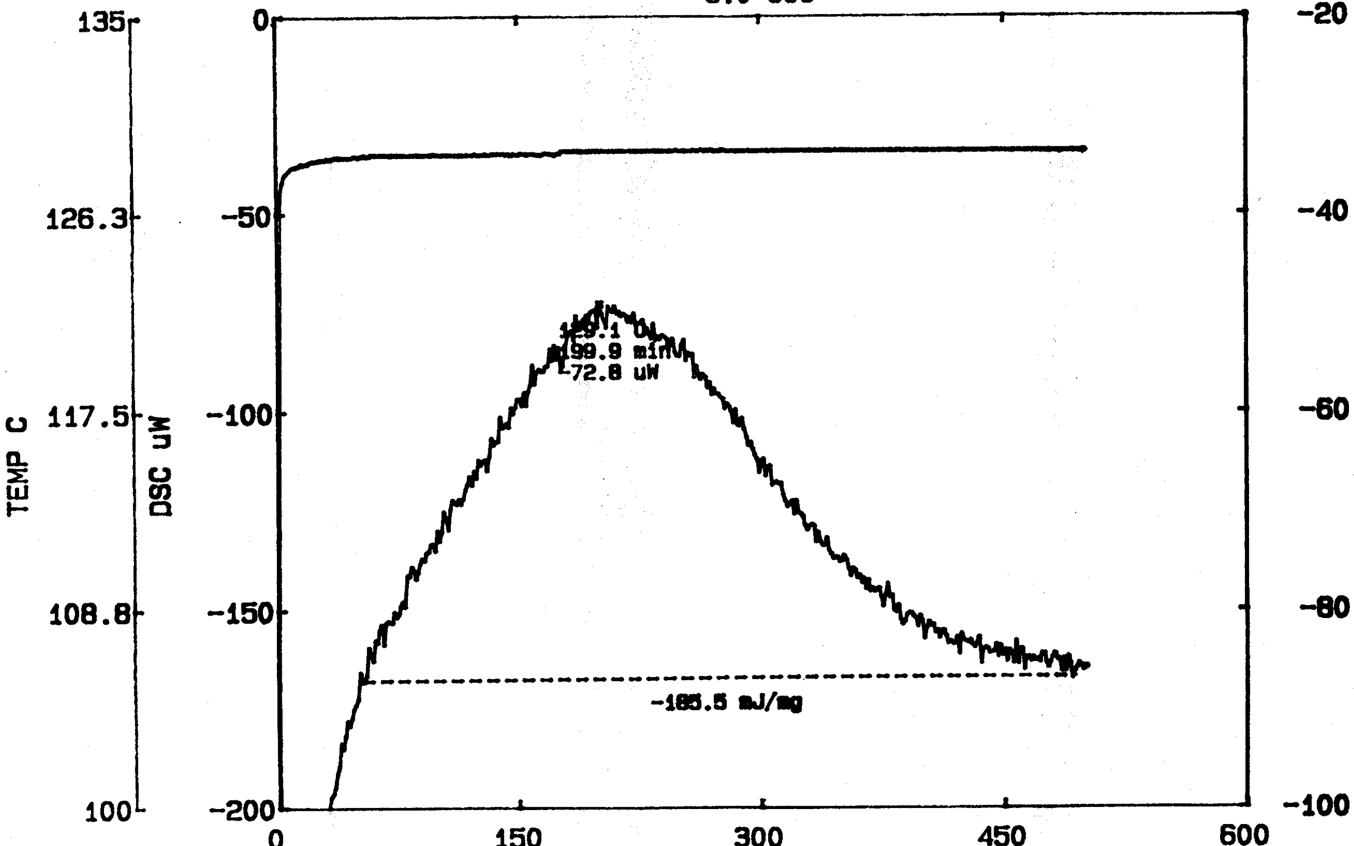


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Figure 1a
230 C

DSC Integ
<Name>
mach.8
<Date>
93/02/18 12:25

<Sample>
PR-500 230
PR-500 3.954 mg
(3.954 mg)
<Reference>
air
0.000 mg

<Comment>
isothermal 230

<Sampling>
0.5 sec

<Temp.program[C] [C/min] [min]>
1* 25.0- 230.0 100.00 90.00
<Gas>
0.0 ml/min
0.0 ml/min

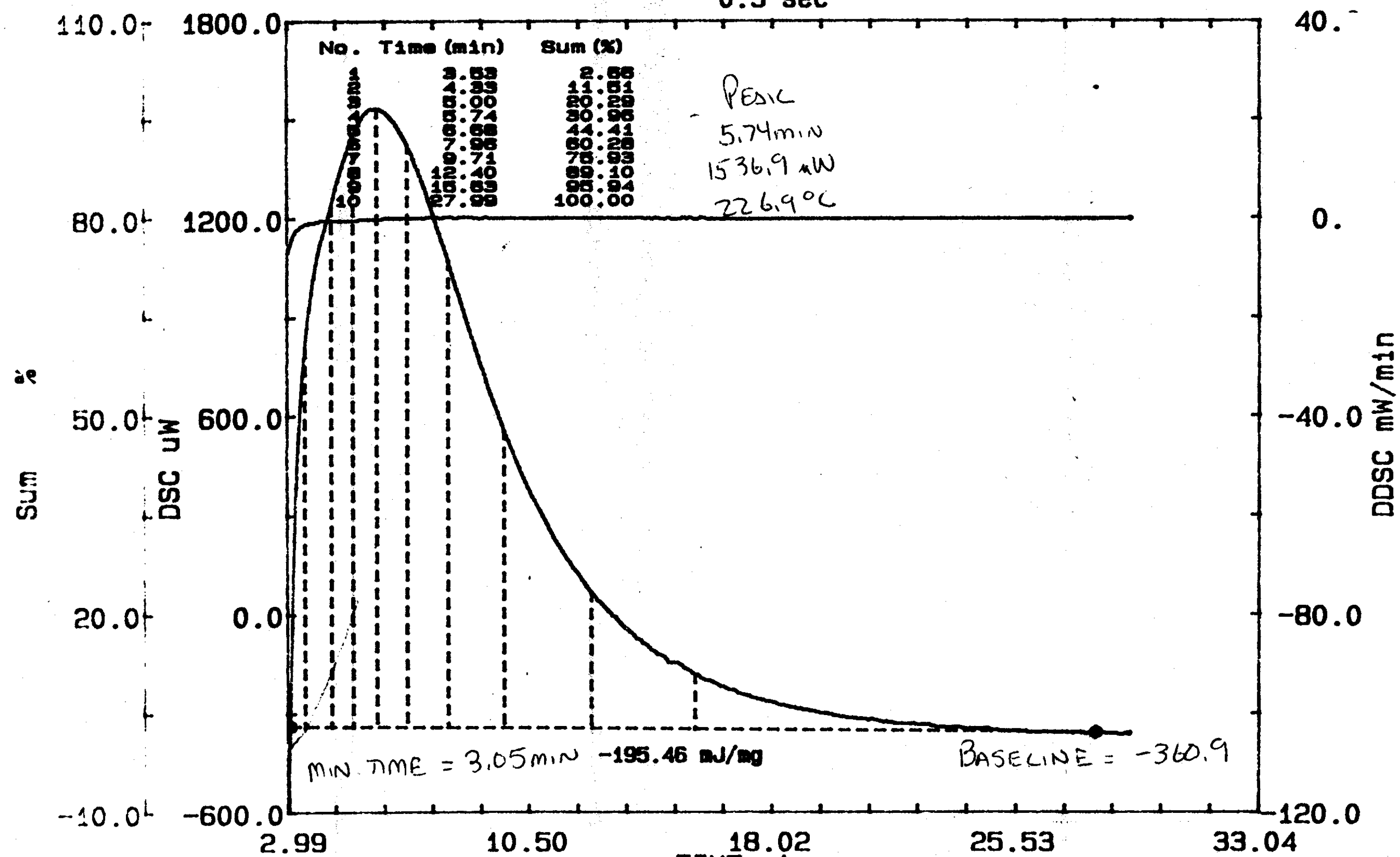

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Figure 2
Heat of Reaction vs Isothermal Temp

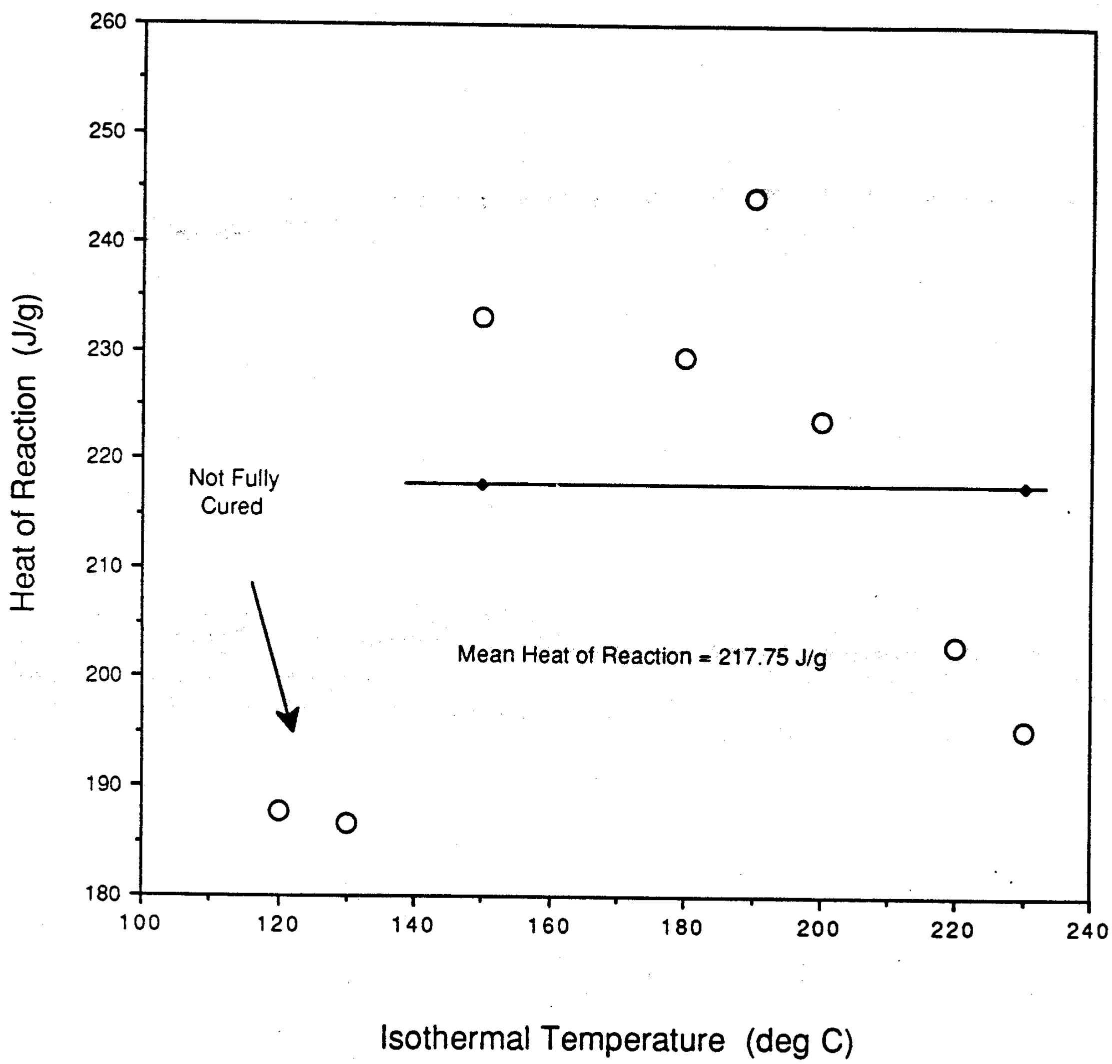


Table 4
Constants for Kinetic Cure Model

$$\frac{d\alpha}{dt} = \left(k1 + k2\,\alpha^{m}\right) * (1 - \alpha)^{n}$$

where: α = Extent of Reaction

$k1$ & $k2$ = Arrhenius functions of temperature

e.g. : $k1 = A1 \exp\left(\frac{-E1}{RT}\right)$

m,n = Exponential constants

A1 (s-1)	=	77954
E1 (J/mole)	=	76285
A2 (s-1)	=	1136
E2 (J/mole)	=	51075
m	=	0.7043
n	=	1.1607

Figure 5
PR-500 Reaction Rate vs Time
Data vs Model Equation Fit
(at 220 C and 230 C)

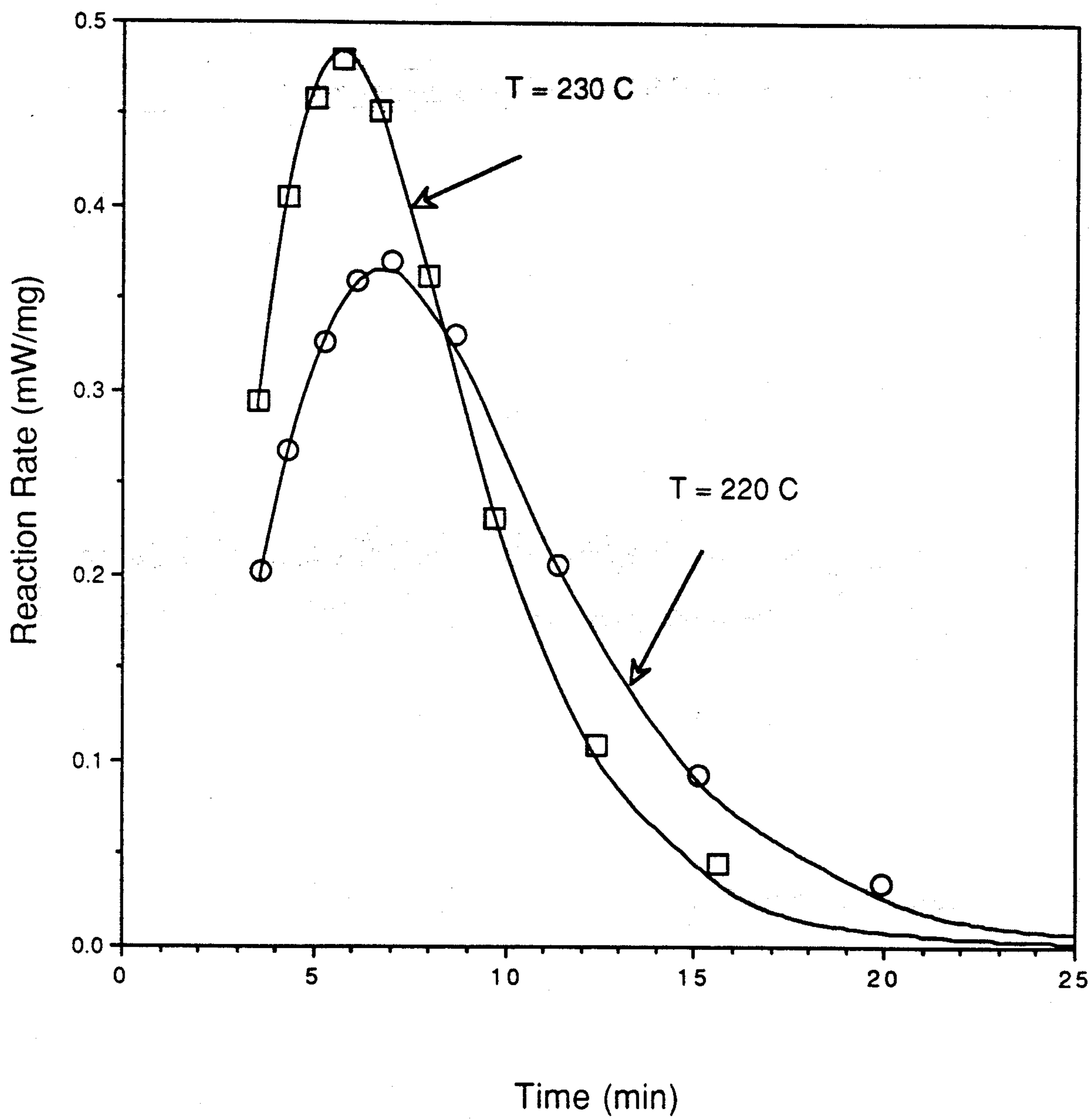
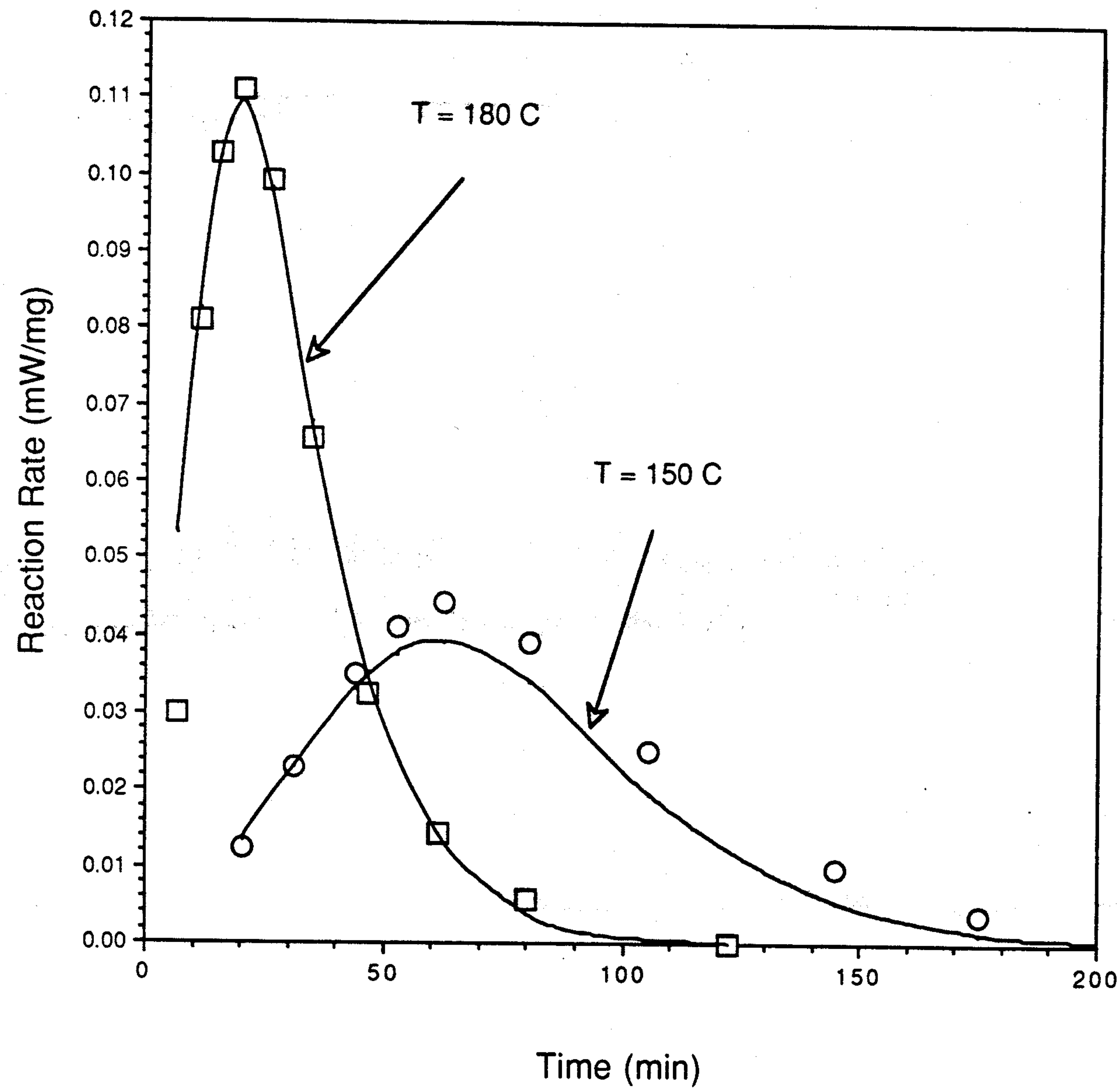


Figure 7
PR-500 Reaction Rate vs Time
Data vs Model Equation Fit
(at 150 C and 180 C)



PR-500 Time vs Viscosity

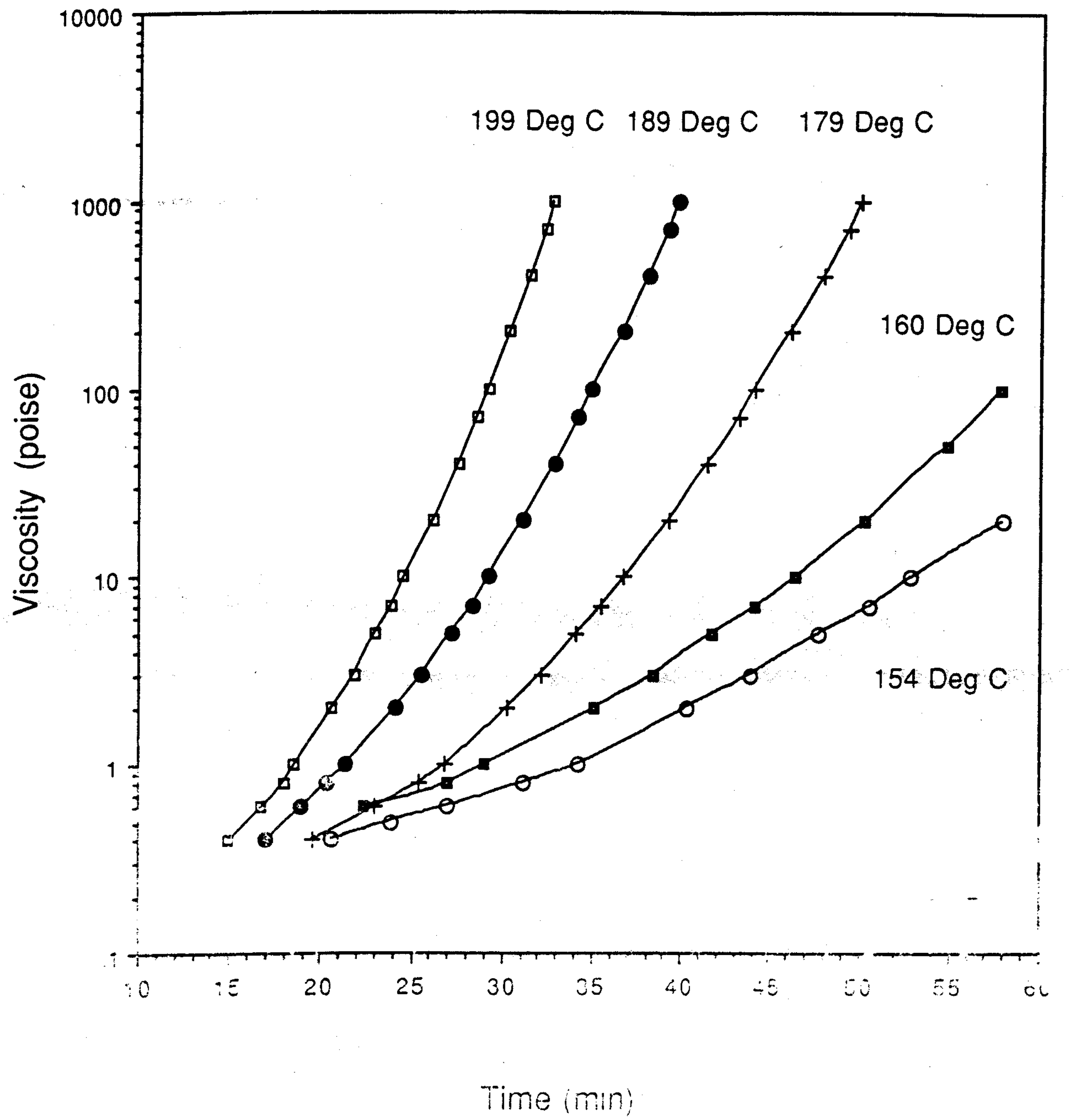


Table 8

Constants for Equation 6

$$\ln(\eta) = \frac{1}{(A_1 + A_2 * Temp) + ((B_1 + B_2 * Temp) * \alpha)}$$

where: η = Viscosity in Centipoise

Temp = Temperature in Kelvin

α = Extent of Reaction (0 $\rightarrow$ 1.00)

A_1, A_2, B_1, B_2 = Constants

A1 =	-2.823
A2 =	0.007174
B1 =	2.539
B2 =	-0.006448

Figure 10
PR-500 Viscosity Data with Model Equation Fit