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**Development of a Pressure Sensitive Paint System With Correction
For Temperature Variation**

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DEVELOPMENT OF A PRESSURE SENSITIVE PAINT SYSTEM WITH CORRECTION FOR TEMPERATURE VARIATION

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ABSTRACT:

Pressure Sensitive paint (PSP) is known to provide a global image of pressure over a model surface. However, improvements in its accuracy and reliability are needed. Several factors contribute to the inaccuracy of PSP. One major factor is that luminescence is temperature dependent. To correct the luminescence of the pressure sensing component for changes in temperature, a temperature sensitive luminophore incorporated in the paint allows the user to measure both pressure and temperature simultaneously on the surface of a model. Magnesium Octaethylporphine (MgOEP) was used as a temperature sensing luminophore, with the pressure sensing luminophore, Platinum Octaethylporphine (PtOEP), to correct for temperature variations in model surface pressure measurements.

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INTRODUCTION:

Measuring surface pressure on a wind-tunnel model is an important analytical tool in fluid mechanics. The most common technique used to measure pressure is the use of pressure taps. The use of pressure taps is a complex and expensive process. Efforts to find more effective ways to measure model surface pressure have lead to the development of pressure sensitive paint (PSP).

Pressure Sensitive Paint is a luminescent paint which consist of a luminophore (fluorescent or phosphorescence chemical) that is dissolved in a polymer/solvent matrix. The luminophore is chosen from those which are quenched by oxygen. The paint mix is applied to the surface of the model and allowed to cure. The pressure is then determined by measuring the light emitted from the illuminated model. The intensity of the emitted light is inversely proportional to the oxygen's partial pressure, and may be represented by a modified form of the classical Stern-Volmer equation.

$$\frac{I_{ref}}{I} = A + BP \quad (1)$$

The " I_{ref} " is the emission intensity at some reference pressure. " I " equals the emission intensity at air pressure " P ". " A " is the y-intercept and " B " represents the slope of the plot of I_{ref}/I vs. pressure.

When using a PSP in a wind tunnel, I_{ref} is experimentally measured and a calibration curve is established by measuring " I " as a function " P ", using pressure taps on the model to measure the calibration pressures.

Peterson and Fitzgerald first reported the use of fluorescence quenching by oxygen for flow visualization of oxygen and nitrogen gas streams, but did not extend their concept to air pressure measurements (1). Russian researchers published the use of PSP for air flow visualization and pressure measurement in wind tunnels (2). NASA-Ames in conjunction with the University of Washington, used platinum octaethylporphine in a polydimethylsiloxane paint matrix for luminescent barometry in a wind tunnel (3). Crites of McDonnell Douglas, presented a thorough summary of measurement techniques based on the oxygen quenching of the fluorescence and phosphorescence luminophores (4).

Pressure Sensitive Paint has proven to be a valuable technique for measuring global pressure, but the accuracy and reliability has not yet been established. Some of the deficiencies that need to be remedied are: (1) PSP luminescence is temperature dependent. (2) All PSP's undergo some photodegradation, but there are some that are worse than others. (3) PSP luminescence is illumination intensity dependent, and an internal reference luminophore is needed to correct for variations in illumination.

We have chosen to focus our research efforts on developing a pressure sensitive paint system to correct for model surface temperature variations.

Research Plan. The conceptional approach of our research is to incorporate a luminophore in the paint which responds only to temperature changes and thus enable the user to measure temperature at any point on the model surface. By knowing the surface temperature and the emission/temperature function for the pressure sensing luminophore, a correction may be made

for the effect of temperature on the pressure sensing luminophore. Candidate temperature sensing luminophores (TSL) that are compatible with proven pressure sensing luminophores (PSL) will be investigated.

There are certain requirements that a TSL must have for it to be considered a compatible luminophore. First, the excitation wavelength of the TSL must be compatible with the excitation wavelength of the PSL. The emission wavelength of the TSL must not overlap the emission wavelength of the PSL. The emission peaks should be separated by at least 50 nm. The TSL must be chemically compatible with both the PSL and the paint matrix. Finally, a good TSL must be spectroscopically compatible with the PSL. This means that one luminophore must not excite the other luminophore.

EXPERIMENTAL:

Chemicals: Radelin 1807-Zinc Cadmium Sulfide [(Zn,Cd)S:Ag:Ni] (Luxton Co., Mountain View, CA.) were used as supplied without further purification. The phosphors of Ruthenium (II)-(4,7-diphenyl-1,10-Phenanthroline), Platinum octaethylporphine (PtOEP) and Magnesium Octaethylporphine (MgOEP), (Porphyrin Products Inc., Logan, Utah) were used as supplied. Polymers used in paints included Poly(2-ethylhexylmethacrylate-co-isobutylmethacrylate) (University of Washington, Seattle, WA), and silicone rubber (RTV-118, General Electric Co.). Solvents (toluene and acetone) were analytical grade or better (Sigma Aldrich Co.).

The dual luminophore paint was prepared as following: 500 ppm of PtOEP and 300 ppm of MgOEP were dissolved in a 1 part IEMA (polymer) to 10 part toluene.

Method: Two proven pressure sensing luminophores, Ruthenium bathophenanthroline (RuB) and Platinum octaethylporphine (PtOEP), were considered in this study. Candidate temperature sensing luminophores were selected from published spectral characteristics. These published properties were compared to spectral characteristics of the two PSL's as shown in Table I. Two of the phosphors; Radelin 1807-Zinc Cadmium Sulfide [(Zn,Cd)S:Ag:Ni], and the Magnesium octaethylporphine [MgOEP] were chosen for study with either of the two pressure sensing luminophores.

Candidate luminophores were tested by studying each of them separately. The luminophore (either the TSL or PSL) was dissolved in a solvent/polymer matrix and sprayed on a square piece of aluminum, the material of the model, and then allowed to cure. Spectral analyses were run on a Perkin Elmer LS50B spectrofluorimeter. The emission and excitation spectra were determined for each sample. The degree of oxygen quenching was determined by measuring emission intensity as a function of air pressure in the sample cell. Emission intensity as a function of air pressure was measured for 6,8,10, 12, and 14.7 psia at 25, 30, 35, 40, and 45°C.

RESULTS & DISCUSSION

The Radelin-1807 phosphor proved to have a poor temperature response ($\Delta E/\Delta T \approx 2$ unit/°C). Also, this TSL was not compatible with either the Ruthenium bathophenanthroline or the Platinum octaethylporphine, due to unacceptable spectral overlap. The MgOEP phosphor showed acceptable temperature sensitivity results

($\Delta E/\Delta T = 18.8$ units/°C) (Figure 3). Preliminary measurements of temperature response suggested that MgOEP as a TSL would correct for temperature variation with the pressure sensing

luminophore PtOEP.

The MgOEP and PtOEP (dissolved in IEMA/Toluene) as dual luminophores were studied on the LS50B. MgOEP fluoresces at 580 nm and can be excited by light around 407 nm. PtOEP can be excited at 382 nm and emits at 644 nm, this is 60 nm away from MgOEP. The emission and excitation spectra of the two are shown in Figures 1 and 2.

Oxygen Quenching. Oxygen quenching was measured by reading the emission intensity output at 5 different air pressures. This enabled the creation of Stern-Volmer Plots (Figure 4) at various temperatures from 25°C to 45°C. From this data, the intercepts and the slopes of the Stern-Volmer plots at each temperature were established (Figure 4).

As may be seen from Figure 4, both the slope and the intercept change with temperature because I_{ref} at 25°C was used for all plots. Since both the intercept and slope change, it is necessary to establish their temperature relationship. A plot of intercept vs. temperature and a plot of slope vs temperature are shown in Figures 5 and 6. Although the changes in these two Stern-Volmer parameters versus temperature are not exactly linear, to a first approximation a linear function may be assumed.

Temperature Response. Emission intensity as a function of temperature for the MgOEP, at different pressures is shown in Figure 3. The emission intensity from the paint at 580 nm was read, and the surface temperature was calculated using the equation

$$T = -\frac{I-a}{b} \quad (2)$$

where a = intercept and b = slope of the plot of average emission versus temperature. This plot shows that MgOEP is independent of pressure, because of the similarity of each line (Figure 3).

To exemplify the improvement of accuracy by this dual luminophore, we compare a system without correction to one using a temperature correction. Suppose there is an unknown temperature increase during the experiment, but we are assuming that the temperature has remained at 28°C. The emission intensity for PtOEP was read to be 155 units and that for MgOEP to be 1287 units. Since we are operating off the Stern-Volmer calibration curve at 28°C (Figure 4), we would calculate the pressure to be 16.1 psia using Equation 1. This would result in a 61% error in the calculated pressure, since the experimental pressure value was actually 10 psia. Using the same emission intensity as above for both MgOEP (1287) and PtOEP(155). We apply temperature correction (Equation 2) to the MgOEP emission; we calculate the corrected temperature to be 36.4°C. From Figure 5 we use the corrected intercept equation to calculate a new corrected intercept "A", to be 0.596. We use the corrected slope equation (Fig. 6) and calculate the new slope "B", to be 0.106. With the new intercept and the new slope, we determine the new corrected pressure to be 10.8 psia. Since the experimental pressure was 10 psia, this represents an 8% error compared to an error of 61% without correction. This 8% error is due to a combination of experimental error and our assumptions regarding linearity of the data.

CONCLUSION

Although a dual luminophore, temperature/pressure sensing paint gives more accurate measurements of pressure at a model surface. This paint combination still has two deficiencies that need further investigation. The photodegradation of MgOEP at 300 ppm and PtOEP at 500

ppm needs to be improved. The photodegradation decay slope of this formulation is -2.18 intensity units per minute. This might be improved by changing the ratio of the concentrations of both luminophores without affecting the intensity output.

Due to the different excitation peaks of both the MgOEP (407 nm) and PtOEP (382 nm), a broad band filter must be used for lamp illumination in a wind tunnel setting.

We have shown that the inclusion of a temperature sensitive luminophore in a PSP can significantly improve accuracy when changes in temperature occur. This will enhance the accuracy of global pressure measurements, and bring us closer to the goal of using PSP for accurate, discrete pressure measurements, an essential step towards replacing pressure taps.

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TABLE I

TEMPERATURE INDICATING PHOSPHORS

**** Literature Study ****

PHOSPHOR	EXCITATION WAVELENGTH	EMISSION WAVELENGTH	PtOEP Em= 644 nm COMPATIBLE	Ru(Ph ₂ phen) ₃ ²⁺ Em= 600 nm COMPATIBLE
EuTTA	345 nm	612 nm	maybe	no
Mg ₄ (F)GeO ₆ :Mn	290 nm	658 nm	no	yes
La ₂ O ₂ S:Eu	254 nm	514 nm	yes	yes
Radelin 1807, (Zn,Cd)S	365 nm	540 nm	yes	yes
Sylvania 243, Sr ₂ P ₂ O ₇ :Sn	270 nm	460 nm	no	yes
MgOEP	407 nm	580 nm	yes	maybe
Conducting Polymers	440 - 490 nm	630 - 670 nm	maybe	maybe

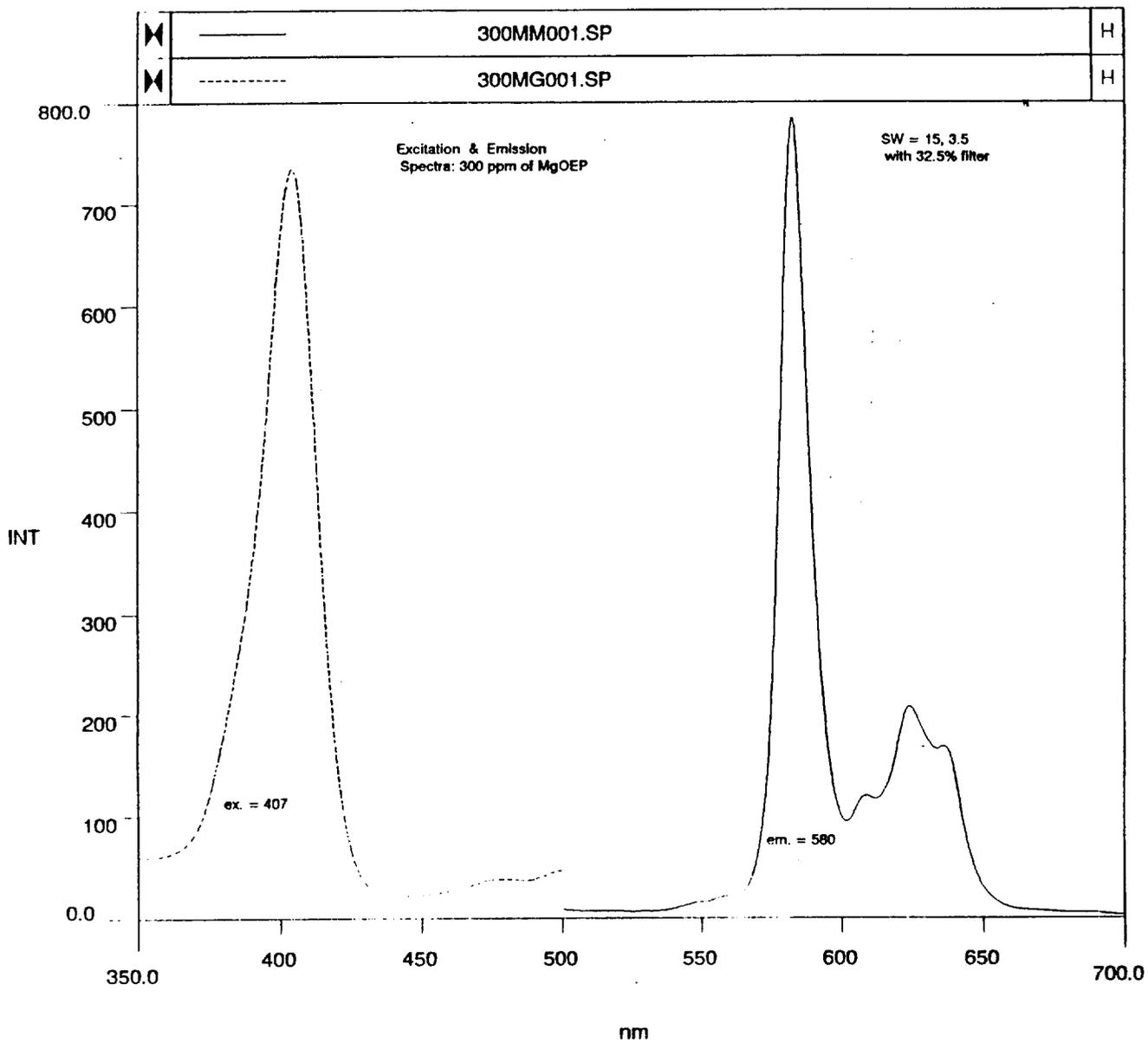


Figure 1. Excitation and Emission Spectra of MgOEP

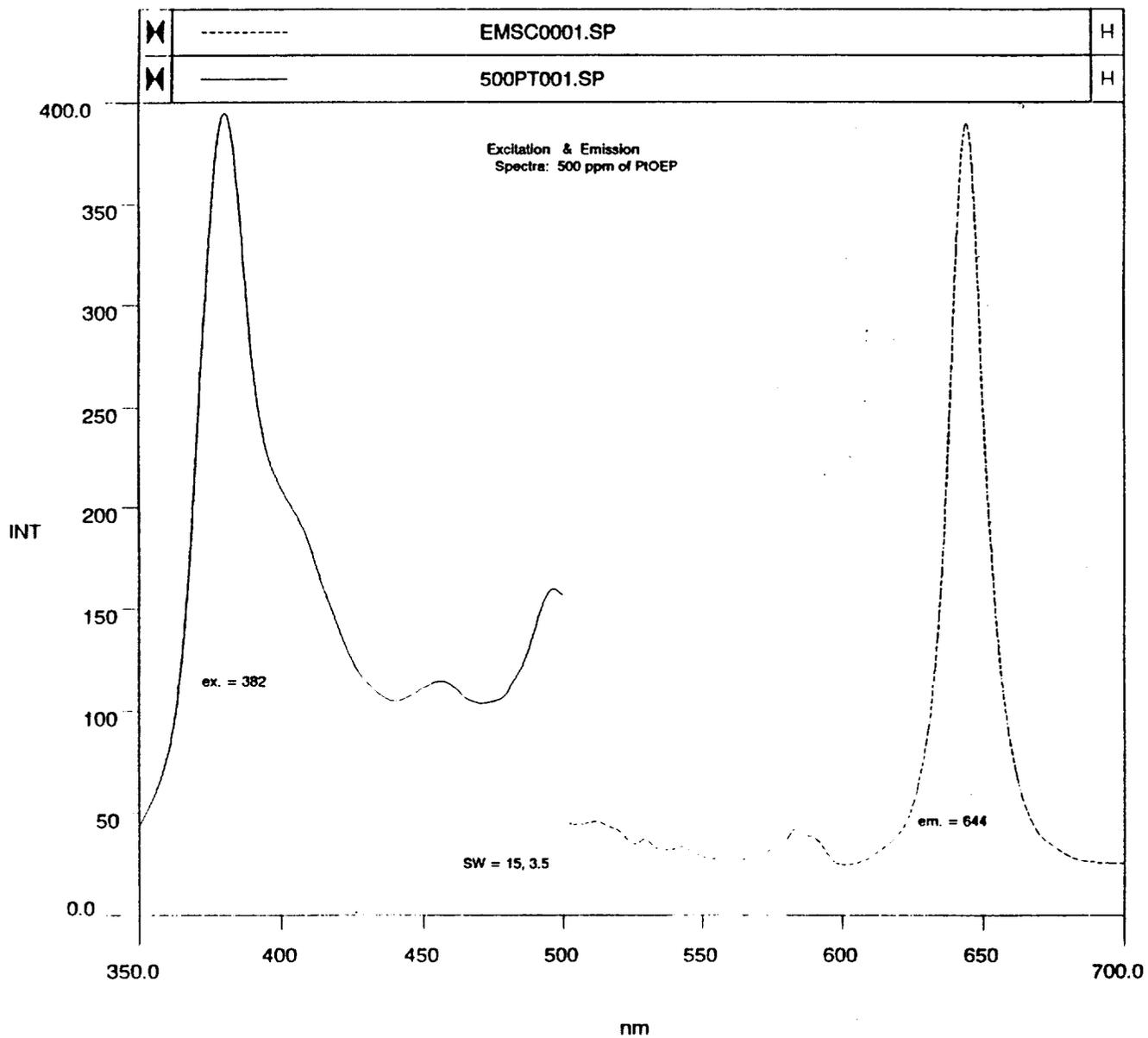


Figure 2. Excitation and Emission Spectra of PtOEP

Temperature Response at Different Pressures
(1 part HEMA/10 part Tol., PtOEP (500ppm) & MgOEP (300ppm))

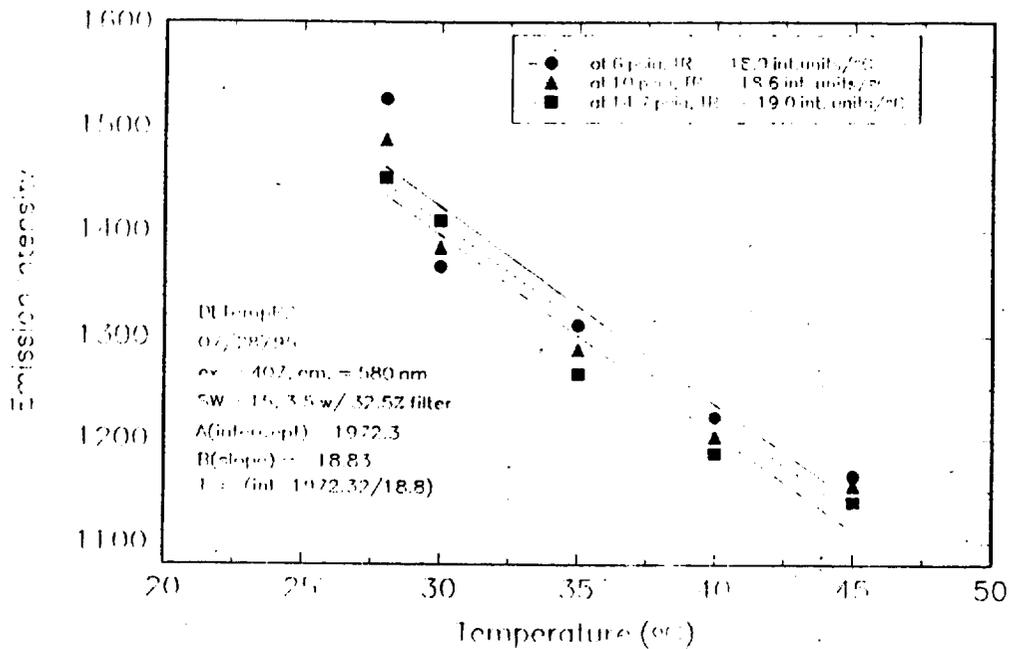


Figure 3.

Stern-Volmer Plot at Different Temperatures
(1 part HEMA/10 part Tol.), PtOEP (500ppm) & MgOEP (300ppm)

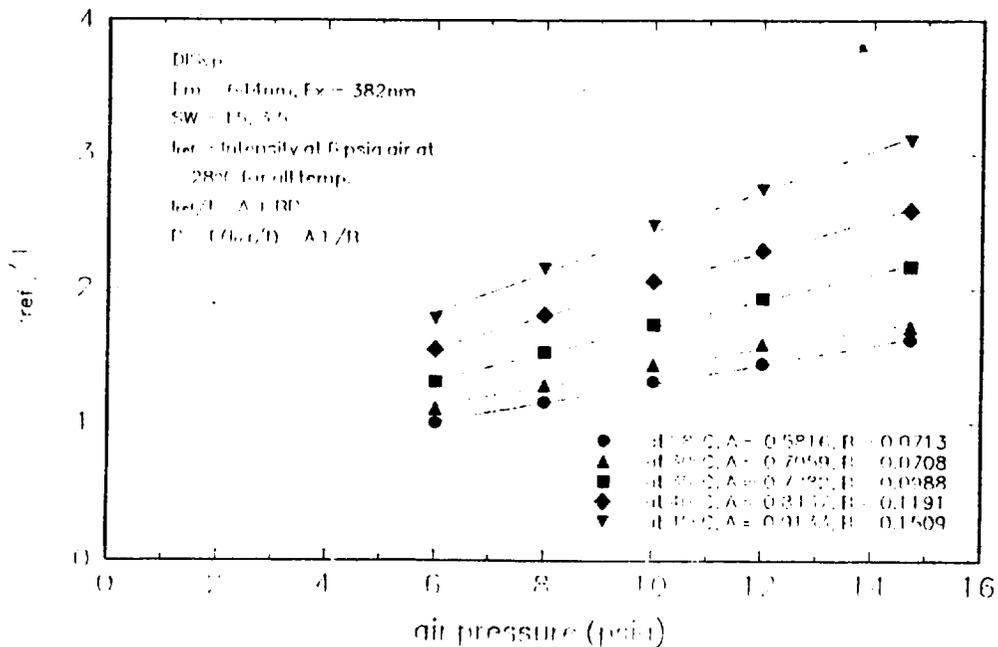


Figure 4.

Stern-Volmer Intercept for PEOEP
 (1 part IEMA/10 part Tol.), PtOEP (500ppm) & MgOEP (500ppm)

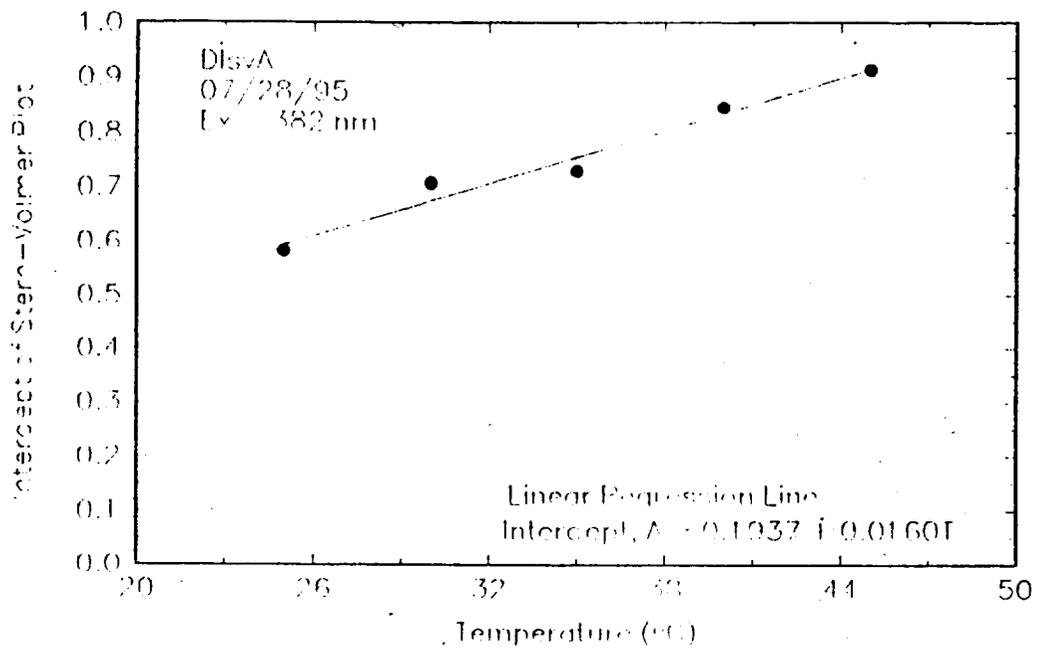


Figure 5.

Stern - Volmer Slope for PtOEP
 (1 part IEMA/10 part Tol.), PtOEP (500ppm) & MgOEP (300ppm)

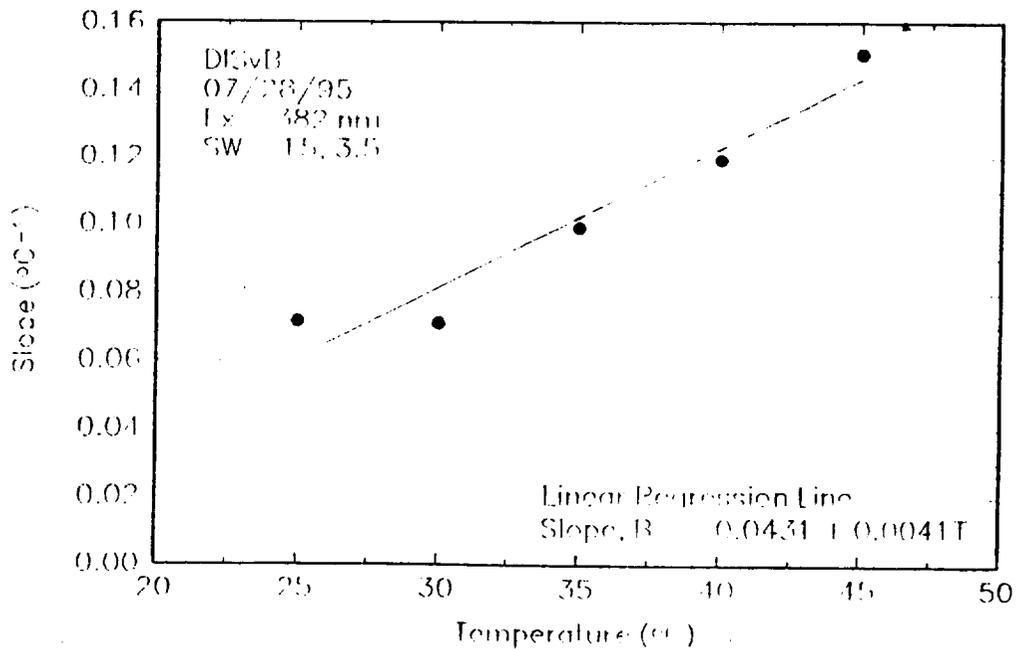


Figure 6.