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ROCHESTER INSTITUTE  
of TECHNOLOGY

Diffusion of the Thiosulfate Ion Out  
of Photographic Film During Washing

A thesis submitted in partial satisfaction of the  
requirements for the degree Master of Science  
in Photographic Science and Instrumentation

by

Kenneth Robert Haring

Under the supervision of  
Professor B. H. Carroll

1970

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DIFFUSION OF THE THIOSULFATE ION OUT  
OF PHOTOGRAPHIC FILM DURING WASHING

ABSTRACT - The thiosulfate ion does not freely diffuse out of a hardened photographic gelatin emulsion. Salts in the washing water displaces the adsorbed thiosulfate ions and allows them to freely diffuse out of the emulsion. The effect of temperature upon the diffusion of the thiosulfate ion is on the order of other diffusion processes. The type and amount of hardening also affects the diffusion of thiosulfate. The diffusion of thiosulfate out of the emulsion is fastest when a non-hardening fixer is used. The use of an alum hardening fixer results in slower diffusion than with formaldehyde prehardening.

When photographers began using sodium thiosulfate as a fixing agent for photographic film, the problem of removing it from the emulsion began. Failure to do so will, in time, cause the silver image to fade. The usual method of removal is by washing the film with water. The rate with which the thiosulfate leaves the film is dependent upon the diffusion of the thiosulfate ion out of the gelatin, for this is the rate controlling step.<sup>1</sup>

The rate of free diffusion can be expressed by a diffusion constant or coefficient. The value of this constant depends upon the diffusing entity and medium, as well as the temperature. Anything that impedes free diffusion will be shown by a change in the diffusion constant. Adsorption or retention of the thiosulfate ion by gelatin would be such an impediment.

The purpose of this investigation is to derive, by means

of a mathematical model, an expression for the diffusion constant of the thiosulfate ion leaving a photographic emulsion during washing. The diffusion constant is then used to express the effects of the wash water temperature, salts in the wash water, image density, and emulsion hardening.

Several investigations into the washing of photographic materials have been conducted. Early work by Elsdon<sup>2</sup> and Warwick<sup>3</sup> studied the static washing technique of changing the water after equilibrium had been reached. Hickman and Spencer<sup>4</sup> studied continuous washing, but the diffusion equation they put forward and the one mentioned by James and Higgins<sup>5</sup> are of a simplified steady state form not valid for changing concentrations. Blyumberg and Davydkin<sup>6</sup> studied the diffusion of thiosulfate into an emulsion, getting a diffusion constant of  $1.0 \times 10^{-6}$ . For this they derived an equation<sup>7</sup> starting with Fick's second law.

The general equation for all types of diffusion is a second order partial differential equation known as Fick's second law.<sup>8</sup>

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2}$$

where:  $c$  = concentration,  $t$  = time,  $D$  = diffusion constant, and  $x$  = distance

For the solution of a partial differential equation of this type, three initial and/or boundary conditions must be specified. Choosing similar conditions to those used by Blyumberg and Davydkin, but adapting them to diffusion out of an emulsion, an equation for the changing concentration

may be derived.

The three conditions used were based on a model of the film and washing procedure.

- 1) The base of the film is assumed to be impervious to thiosulfate such that none penetrates it.
- 2) The initial concentration is assumed to be constant throughout the film thickness prior to the washing.
- 3) After washing starts, the concentration at the surface of the film is assumed to be zero. This is a valid assumption for the rapid and turbulent water changes associated with spray washing.

The actual derivation is presented in appendix A. The resulting equation for the diffusion constant is:

$$D = - \frac{4 l^2}{\pi^2 t} \ln \frac{\pi^2 \bar{c}}{c_0 R}$$

where: D = diffusion constant, l = emulsion thickness, t = time,  $\bar{c}$  = average concentration,  $c_0$  = initial concentration, and R is a remainder term containing an infinite series

The term R arises out of the mathematical rearranging of the derived concentration equation to get an expression for D. It is a converging infinite series containing D. The value of D is determined iteratively, alternately solving for D and R until the desired accuracy is reached. In actuality, for the cases studied, R can be assumed to be equal to 1.0. This is because the series terms after the first have little effect on the value of R.

## Experimental

The experimental procedure was set up to gather the data on the parameters of the equation. The experimental setup was quite simple and designed to eliminate as many variables as possible. Distilled water was used for washing so that water hardness would not enter in. The water was stored in a plastic bottle and adjusted to a pH of about 7 with NaOH. This was necessary because of dissolved CO<sub>2</sub> in the water. An air pressure of 5 psi was applied to the bottle to force the water out at a constant rate through a Brinks F-0 "Spra-Rite" nozzle. The wash water spray was onto the emulsion side of the film sample.

The film used was 70mm Kodak Aerial Recon Duplicating Film type 8427. It was chosen principally because it does not have any gelatin backing and because it is a relatively simple emulsion. Because duplicating type films receive rough treatment it is possible that there was some hardening of the emulsion during manufacture.

Whether exposed or not, the film was first placed in Kodak HC-110 developer diluted 1 to 31 for 4 minutes at 25°C and then rinsed with water before being placed in the fixing bath. The time in the fixing bath was twice the time it took the film to clear.

After fixing, the surface moisture was blotted from the film with a clean piece of filter paper. The base was then wiped with a damp filter paper and dried. A sample of the film was taken for analysis to determine the initial

thiosulfate concentration. All samples were taken with a hole punch. For initial concentrations, the hole was diamond shaped having an area of  $1/64$  of a square inch. After washing started a circular hole punch having a  $1/4$  inch diameter was used to get samples from which the average thiosulfate concentration in the film was determined. As washing progressed it was necessary to increase the sample size. This was done by punching more holes. The concentration figures were then correlated by expressing them in  $\text{mg./in}^2$  of anhydrous sodium thiosulfate.

At the time that the thiosulfate concentration sample was taken, another sample was taken to determine the emulsion thickness. The thickness was determined by taking a very thin slice off of the edge of the sample with a razor blade and viewing it, while still wet, under a microscope with a micrometer eyepiece. Since this was a difficult and time consuming process, it was done every other time the concentration sample was taken during a washing run. The thickness for the other samples was determined by interpolation.

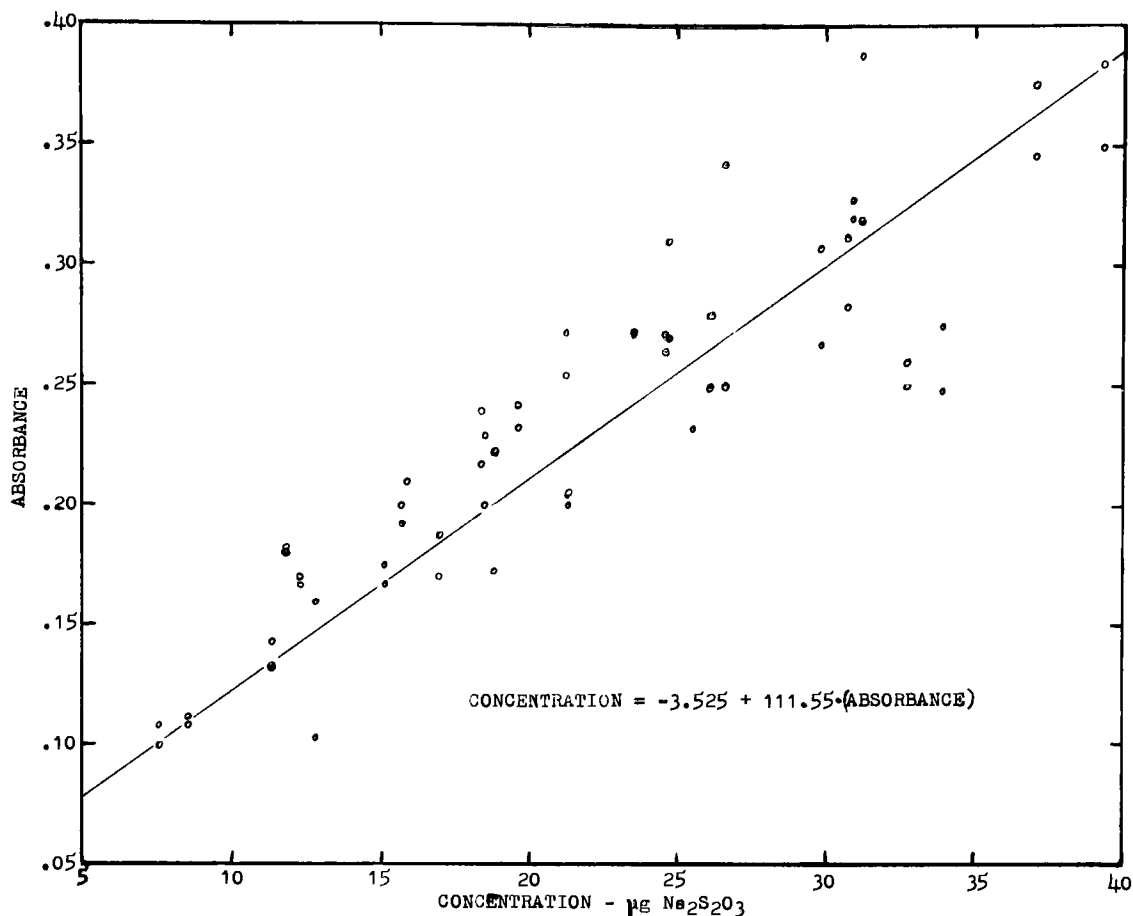
The chemical analysis for the thiosulfate has to be accurate, repeatable, sensitive to small concentrations, and give objective results. For these reasons the method of Warburton and Przybylowicz<sup>9</sup> was used, instead of the method of Crabtree and Ross.<sup>10</sup> The procedure is to extract the thiosulfate from the film sample in a 1 g/l each solution of KI and  $\text{KH}_2\text{PO}_4$ . Sodium borohydride solution is then

added to the extract solution to reduce the thiosulfate to sulfide. Ferric sulfate and p-dimethylaminoaniline solutions are then added which causes the formation of methylene blue.

The amount of methylene blue formed by the film samples was measured with a Coleman Junior Spectrophotometer Model 6D at 665 m $\mu$  and the concentration of the thiosulfate determined. The calibration of the spectrophotometer was done for two conditions. One was for high concentrations, in which the methylene blue solution was diluted 1 to 4 so that the reading did not go off the scale of the instrument. This condition was used only to determine the initial concentration of thiosulfate in the film. The other condition was for lower concentrations, below 15 micrograms of thiosulfate. The procedure was the same in both cases. The absorbance readings of known thiosulfate concentrations were correlated using a least squares technique on an IBM 1620 computer to give two equations, a straight line linear equation for the high initial concentrations and a cubic equation (because it most closely fit the data) for the low concentration data. (See figures 1&2)

With the aid of an IBM Systems 360 computer the data was used to compute the diffusion constant. If, because of experimental error, the concentration of the thiosulfate for long wash times was determined to be negative, it was set equal to 0.001 so that the computer calculations could continue. This value is an order of magnitude smaller than the smallest non-negative concentration.





**fig. 1 High Concentration Calibration Curve**

the smallest non-negative concentration.

The washing setup and experimental runs were designed to obtain diffusion constants for several conditions. The basic setup was for washing at 25°C using a film with no image and a conventional acid hardening fixing bath (Kodak F-5 formula). From this base, experiments were conducted at other wash water temperatures. The effect of image silver was studied with film exposed and developed to an optical density of 0.3 and 1.0. Film hardness was studied using a non-hardening fixer (Kodak F-24), a formaldehyde prehardener (Kodak SH-1) with the non-hardening fixer, and

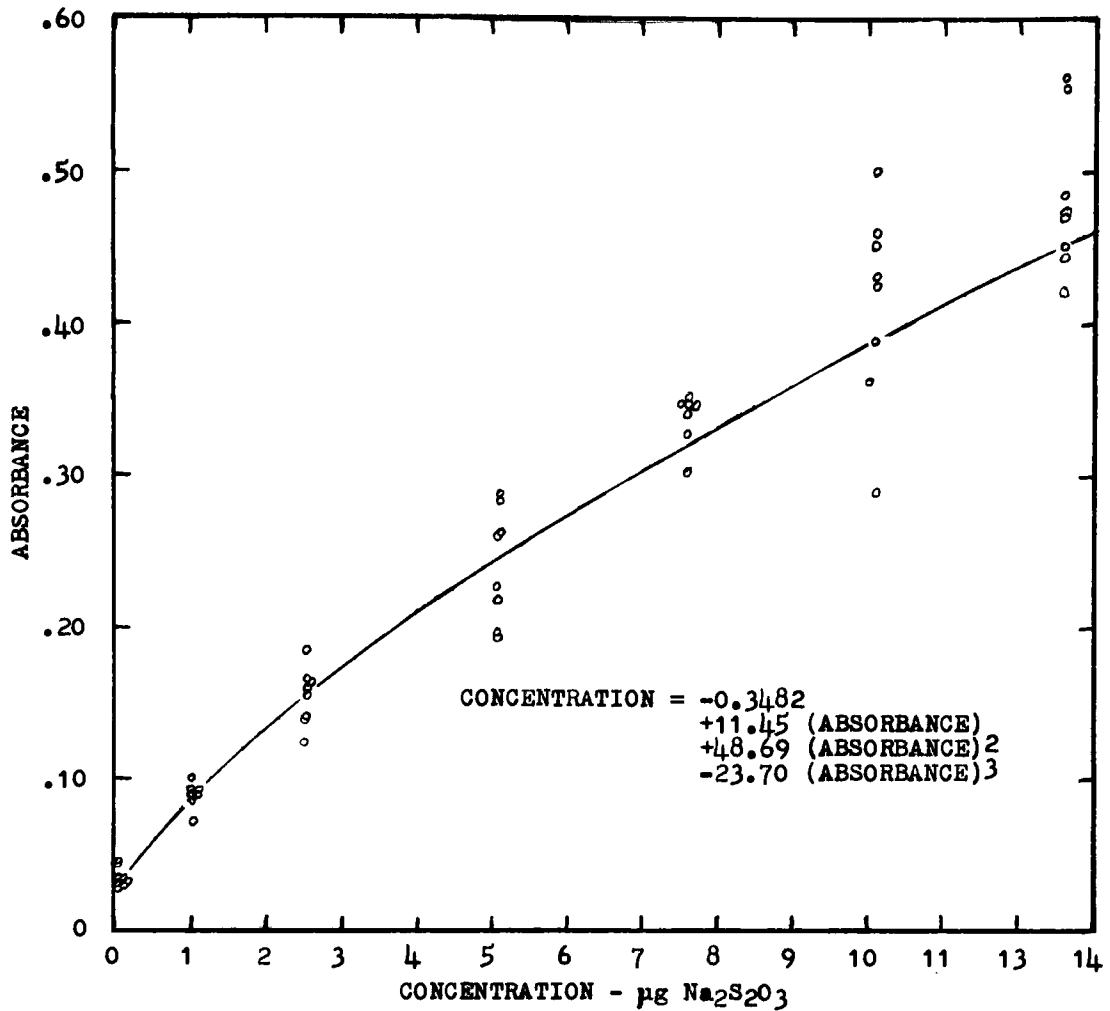


fig. 2 Low Concentration Calibration Curve

an acid hardening fixer that contained twice the amount of hardening agents than the standard F-5

A salt-water wash of 2 g/l each of KI and NaCl was used after an F-5 fixing bath on film with no image silver and with optical densities of 0.3 and 1.0 to study the effect of salt-water washing on the diffusion constant. All of the runs were replicated at least once to determine experimental variability.

## Results

Some of the data gathered in a few of the experiments is presented in appendix B. Substituting the data into the diffusion equation should give a constant value for the diffusion constant for free diffusion. Instead, a linear decrease, when plotted on a log-log scale, of the diffusion constant with time was found. (See figure 3 below)

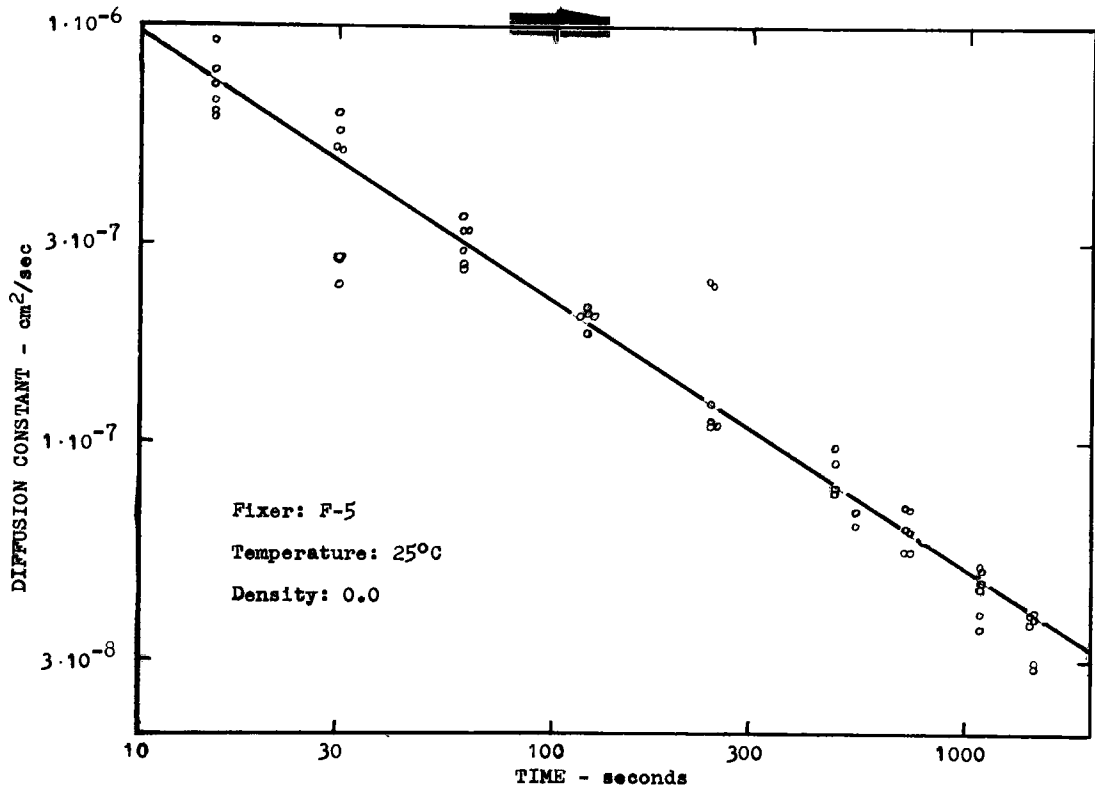


fig. 3 Non-Saltwater Washing

In order to facilitate data interpretation the logarithms of the diffusion constants for each washing run (samples from the same piece of film and initial concentration but with different wash times) and the logarithms of the wash times were correlated by a regression analysis technique. This regression analysis was done on an IBM

Systems 360 Model 91 computer. The results give the parameters of a straight line equation of the form  $\ln D = a + b \ln t$  which may be rearranged to:  $D = e^a t^b$

where: a is the intercept and b is the slope

The regression line for the data is also plotted in figure 3.

The exception to ~~this~~ exponential relationship of the diffusion constant with time is for the saltwater washes. A log-log plot of the data (figure 4) shows that the diffusion constant appears to be a constant for a period of about 60 seconds and then goes to the exponential time relationship.

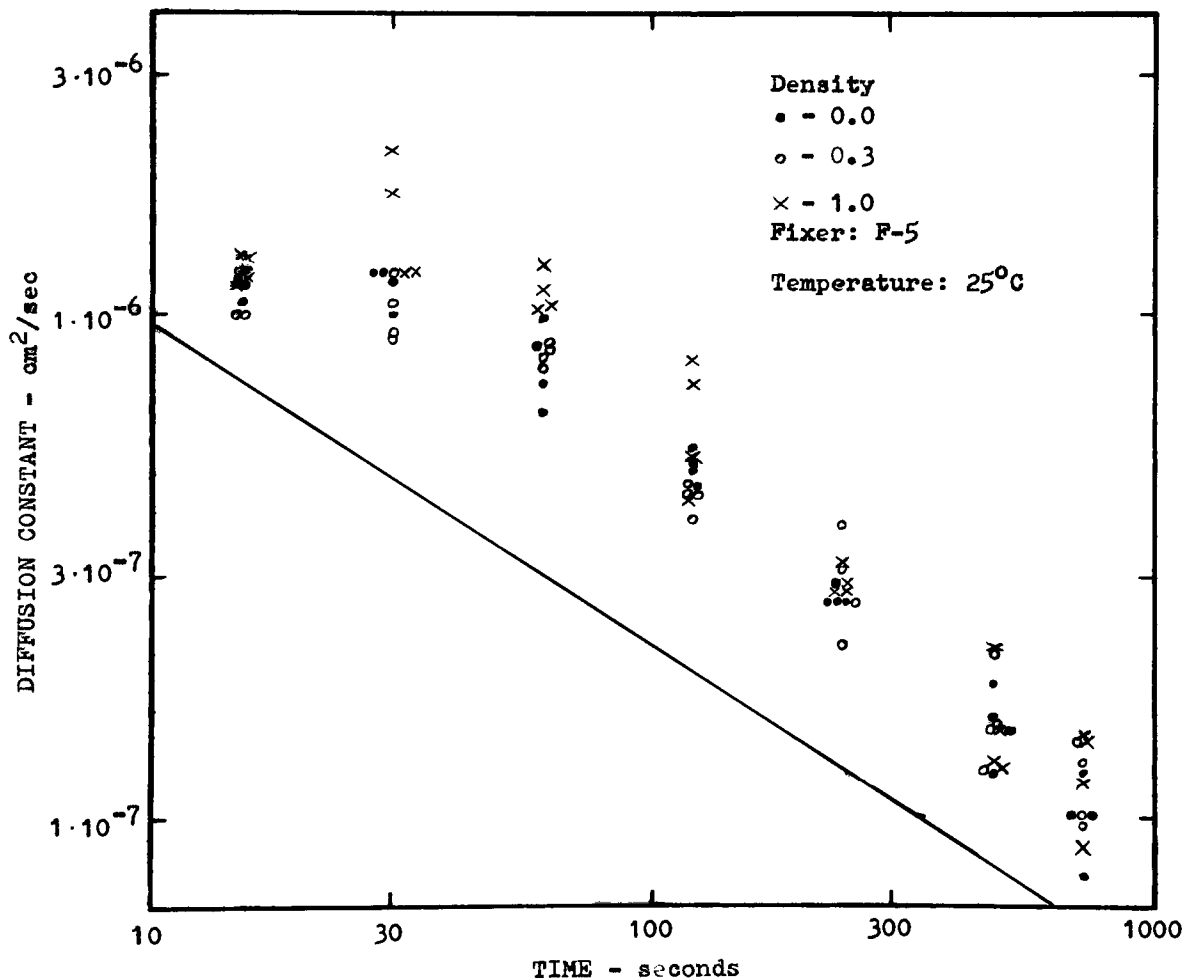


fig. 4 Saltwater Washing

The effect of the image silver upon the diffusion constant is shown in figure 5 for non-saltwater washing and figure 4 for the saltwater washing. As can be seen there is no definite pattern to the data with regards to density. This indicates that image silver has little or no effect upon the diffusion constant.

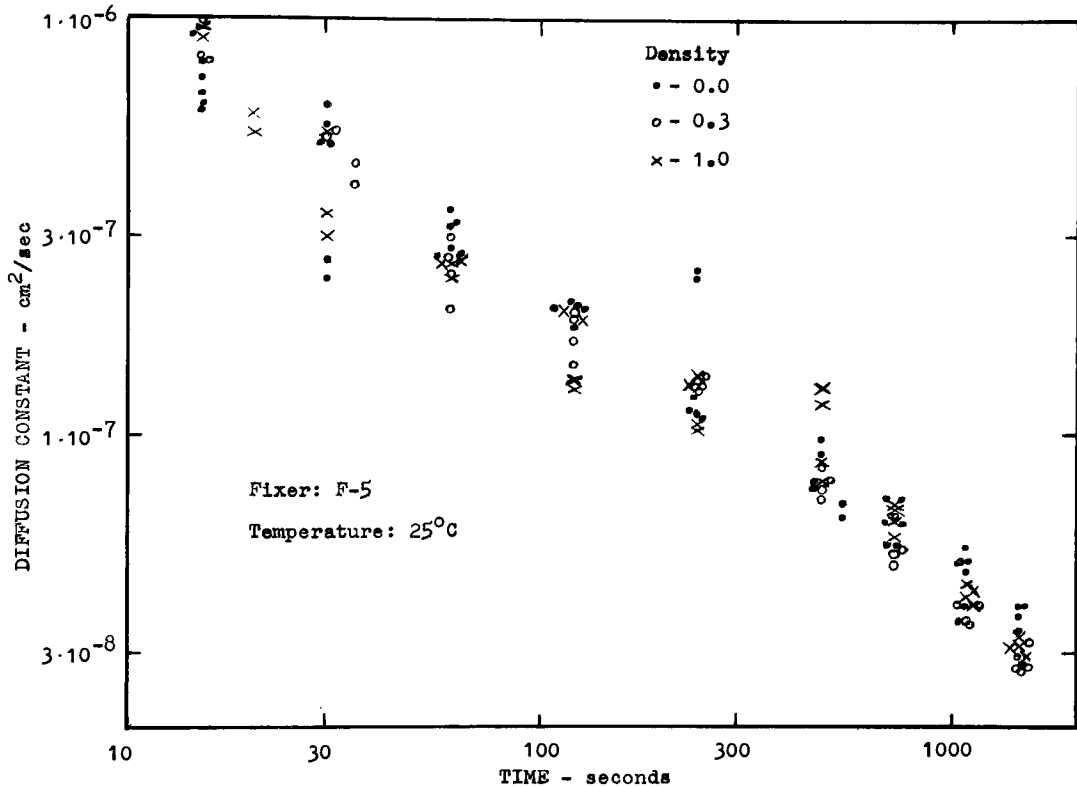
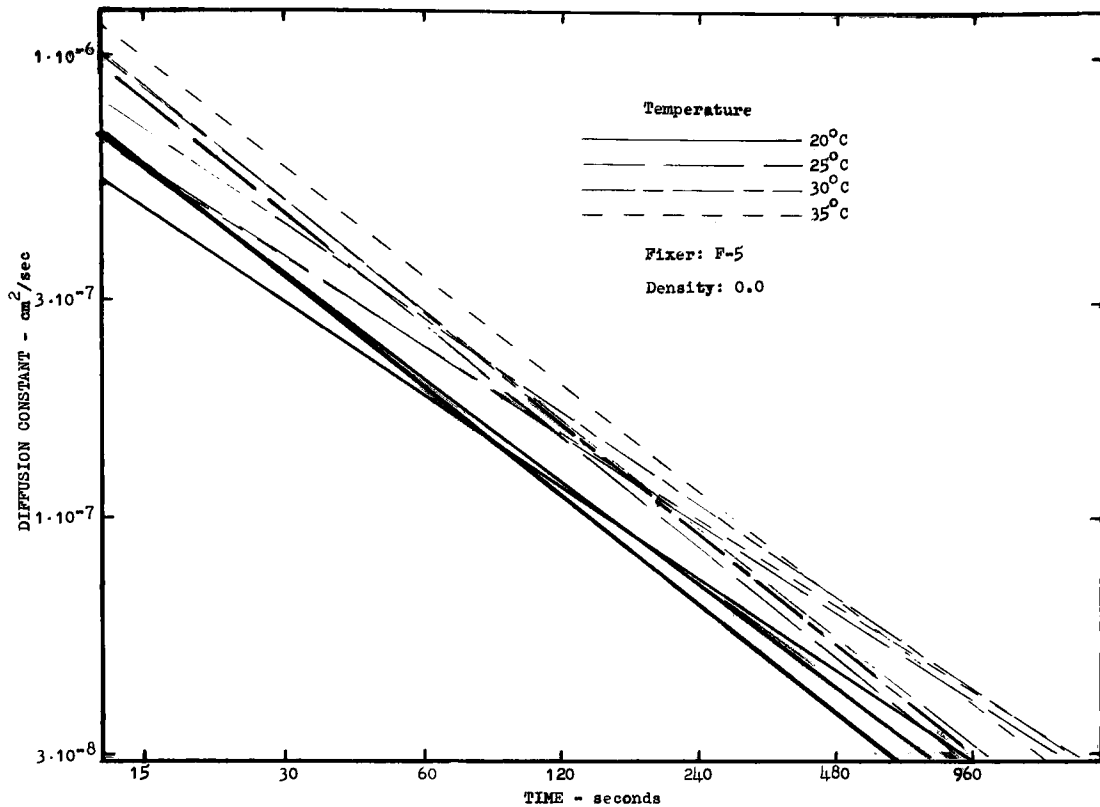


fig. 5 Non-Saltwater Washing of Image Silver

As mentioned, most of the diffusion constant data has a straight line log-log relationship with time. These straight lines are similar in slope for most of the data. This is especially true for the temperature data where the slope is quite similar but the lines are spaced apart with regard to the temperature. The regression lines for the various temperature runs are plotted in figure 6.



**fig. 6** Temperature Variation of Diffusion Constant

Boltaks<sup>11</sup> said that the thermal dependence of a diffusion constant can be expressed as:  $D = D_0 e^{-E/RT}$

where:  $D$  = diffusion constant,  $D_0$  = diffusion constant base,  $E$  = thermal activation energy,  $R$  = gas constant, and  $T$  = Kelvin temperature

Taking the natural logarithm of the equation:

$$\ln D = \ln D_0 - E/RT$$

The equation is now in the form of a straight line  $Y = a + bX$  assuming  $Y = \ln D$ ,  $a = \ln D_0$ ,  $b = -E/R$ , and  $X = 1/T$ . The activation energy  $E$  may be found by plotting the log of the diffusion constant  $D$  against the reciprocal of the temperature  $1/T$ . The graph will be a straight line with the slope equal to  $-E/R$  and the intercept being  $\ln D_0$ . The temperature range studied was not very great and as

figure 6 shows the spacing of the diffusion constant varies. For these reasons, only an approximation of the activation energy can be made. Figure 7 shows a plot of the natural logarithm of the diffusion constant, at about 120 seconds or approximately midway into the wash, versus the reciprocal temperature. A computer regression analysis of the data gives an intercept of  $D = -6.37$  and a slope of  $-E/R = -2.68 \cdot 10^3$ . Using a gas constant  $R$  of  $1.987 \text{ cal/}^\circ\text{K}$  gives an approximate thermal activation energy of 5.3 kilocalories. This is of the proper order for a diffusion process.

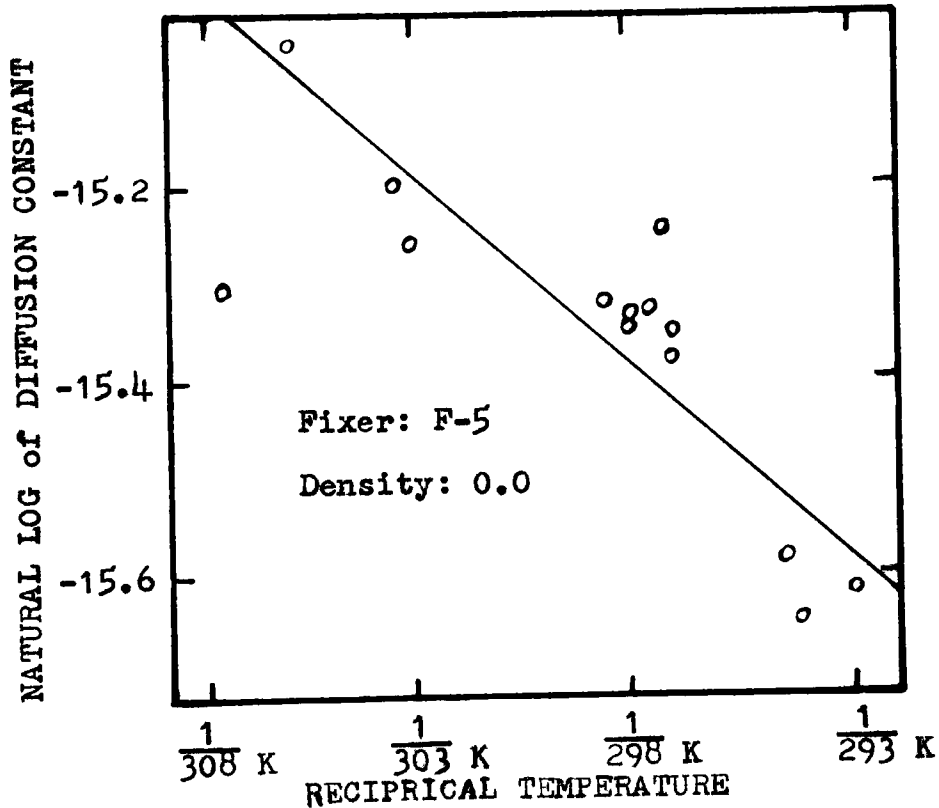


fig. 7 Activation Energy Plot

The effect of emulsion hardness was tested under four different conditions. The standard Kodak F-5 acid hardening fixer, a modified F-5 with 30 g/l of potassium alum instead

of the normal 15g/l, a non-hardening fixer (Kodak F-24), and a formaldehyde prehardener (Kodak SH-1) with the F-24 fixer were all tried. The regression lines for the different experimental runs are presented in figure 8.

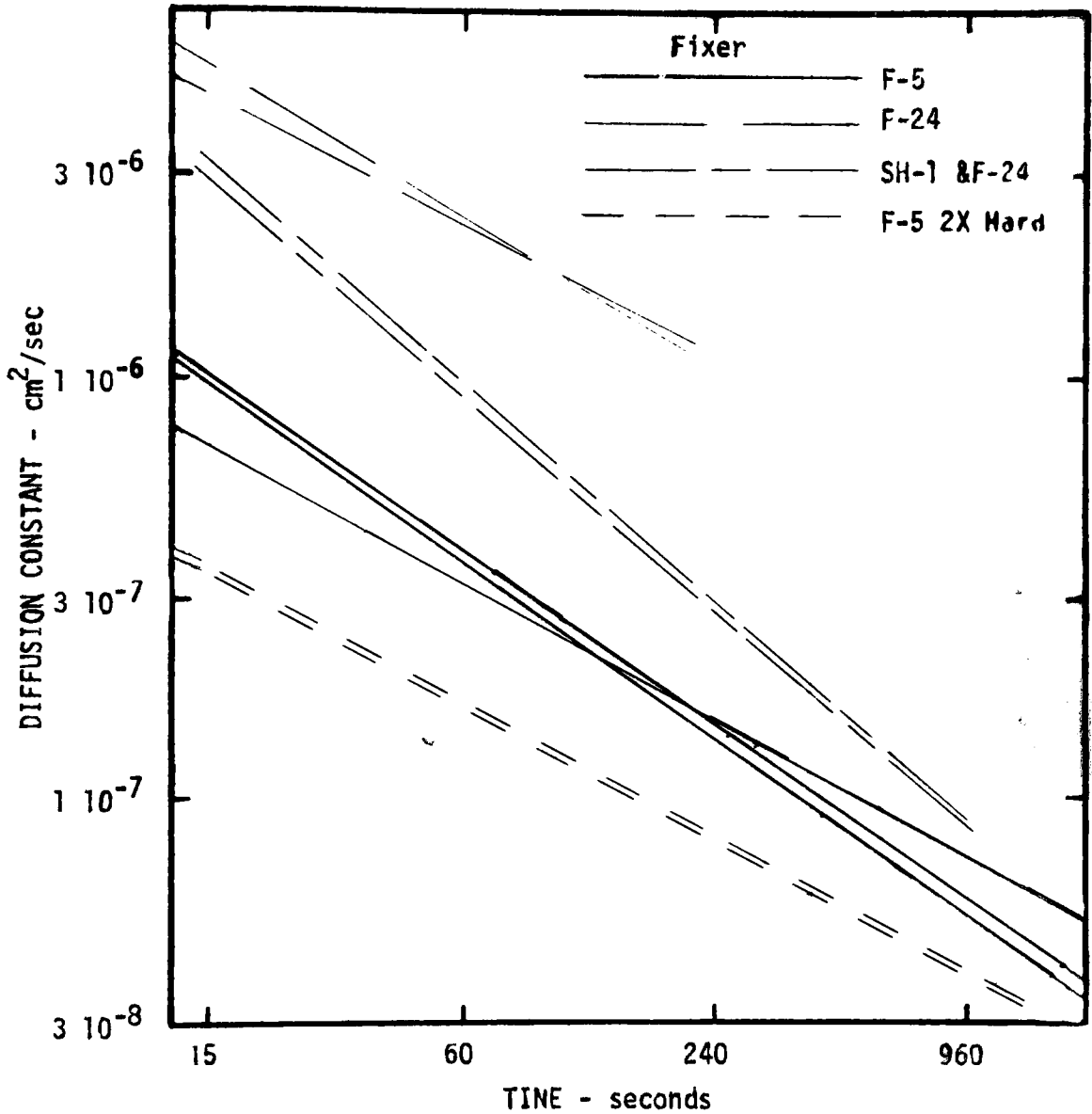


fig. 8 Effect of Hardening on Diffusion Constant

The main effect, as expected, is the more hardening of the emulsion the smaller is the diffusion constant or the slower the diffusion of the thiosulfate ion out of the



emulsion. The use of the acid hardening F-5 fixer results in diffusion about 8 times slower than with the non-hardening F-24 fixer. Doubling the potassium alum in the F-5 slows the diffusion by about 2 times. For the formaldehyde prehardening the slope of the regression line is steeper and the decrease in diffusion from non-hardening is initially not very great. The emulsion hardness was the same as with the F-5 fixer (emulsion thickness approximately 40  $\mu$  wet for both), but the thiosulfate initially leaves the emulsion 3 times faster than with the F-5 fixer. The difference between the diffusion constants then decreases indicating that the formaldehyde hardening allows the thiosulfate ion to be more strongly adsorbed to the gelatin.

#### Conclusion

The principal conclusion to be drawn from the results is that the thiosulfate ion does not diffuse freely out of the gelatin emulsion of the film used but appears to be adsorbed to it, even as soon as 15 seconds after the start of washing. It is not known whether this interference of free diffusion by adsorption occurs in an unhardened gelatin. The difference of the slope for a formaldehyde prehardened emulsion as seen in figure 8 shows that such an emulsion provides for better adsorption by the thiosulfate ion. If the duplicating film used in these experiments had received any formaldehyde type of hardening during manufacture then this might account for the changing of the diffusion constant with time.

In their study of saltwater washing Henn, King, and Crabtree<sup>12</sup> have suggested that the faster removal of thiosulfate from the emulsion was due to displacement of the thiosulfate ion by the salt anion. This would explain the fact that in figure 4 the diffusion constant appears to remain about constant for the first minute of saltwater washing. The salt displaces the thiosulfate until the low salt concentration (0.2% each NaCl and KI) can no longer displace the more firmly adsorbed thiosulfate ions at which time the diffusion constant takes on the exponential relationship with time.

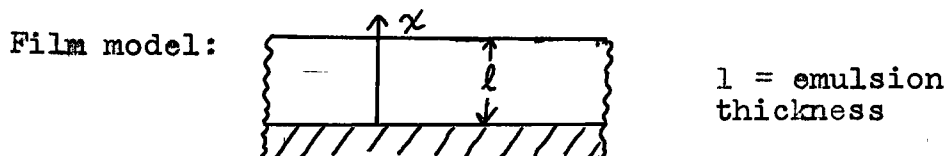
## APPENDIX A

### Derivation of Diffusion Constant

Fick's second law of diffusion is:<sup>13</sup>

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \quad (1)$$

where:  $c$  = concentration,  $t$  = time,  $D$  = diffusion constant, and  $x$  = distance



The base is assumed to be impervious to thiosulfate. This may be expressed by the partial differential equation  $\frac{\partial c}{\partial x} = 0$  at  $x = 0$ .<sup>14</sup> This means that there is no concentration gradient at  $x = 0$  and therefore no thiosulfate will penetrate into the base. The concentration is a function of the distance  $x$  from the base, the washing time  $t$ , and the initial concentration  $c_0$ .

In solving a second order partial differential equation like Fick's second law, three initial and/or boundary conditions are needed. The above partial differential equation will satisfy one boundary condition. An initial condition is the specification that the concentration, over the entire thickness of the emulsion, equals the initial concentration  $c_0$  at time  $t = 0$ .

The final requirement for solution may be met by a boundary condition. With spray washing, the continuous supply of fresh water removes the thiosulfate at the surface

of the emulsion. This may be expressed as the concentration being zero at  $x = l$  for times greater than  $t = 0$ .

If it is assumed that the concentration, being a function of  $x$  and  $t$ , has a general form  $c = X(x) \cdot T(t)$ , then Fick's law, equation (1), may be solved by the technique of separation of variables.<sup>15</sup>

Substituting the assumed concentration equation into eq. (1):

$$X \frac{\partial T}{\partial t} = DT \frac{\partial^2 X}{\partial x^2} \quad \text{or} \quad \frac{\frac{\partial T}{\partial t}}{T} = D \frac{\frac{\partial^2 X}{\partial x^2}}{X} \quad (2)$$

Since both sides of eq. (2) are functions of one variable and are equal, they must be equal to a constant. An examination will show that they are equal if both are 0 or a negative number  $-\rho^2$ .

$$\frac{\frac{\partial T}{\partial t}}{T} = -\rho^2 \quad \alpha^2 \frac{\frac{\partial^2 X}{\partial x^2}}{X} = -\rho^2 \quad \text{where: } \alpha^2 = D$$

These equations can be solved independently.

$$T = e^{-\rho^2 t}, \quad X = \cos \frac{\rho}{\alpha} x, \quad X = \sin \frac{\rho}{\alpha} x$$

From the boundary condition at  $x = 0$  that  $\frac{\partial c}{\partial x} = 0$  it is apparent that this can only be satisfied by  $X = \cos \frac{\rho}{\alpha} x$

This gives the concentration as:

$$c = T \cdot X = e^{-\rho^2 t} \cos \frac{\rho}{\alpha} x$$

The other boundary condition that  $c = 0$  at  $x = l$  for  $t > 0$  will be satisfied if  $\rho = (n + \frac{1}{2}) \frac{\pi \alpha}{l}$  where  $n$  is an integer. Remembering that  $\alpha^2 = D$ :

$$c = e^{-(n + \frac{1}{2})^2 \frac{\pi^2}{l^2} D t} \cos (n + \frac{1}{2}) \frac{\pi}{l} x \quad (3)$$

The initial condition that  $c = c_0$  at  $t = 0$  is incorp-

rated by evaluating eq. (3) at  $t = 0$  and setting the expression equal to  $c_0$ . Since all values of the integer  $n$  are needed to give the concentration, it is necessary to sum up the expression and at the same time incorporate a constant  $K_n$ .

$$c = \sum_{n=0}^{\infty} K_n e^{-(n+1/2)^2 \frac{\pi^2}{l^2} D t} \cos(n+1/2) \frac{\pi}{l} x \quad (4)$$

$K_n$  is determined by evaluating eq. (4) at  $t = 0$  over the range  $0 \leq x \leq l$  and setting it equal to  $c_0$ .

$$c_0 = \sum_{n=0}^{\infty} K_n \cos(n+1/2) \frac{\pi}{l} x$$

Multiplying both sides by  $\cos(m+1/2) \frac{\pi}{l} x$  and integrating with respect to  $x$  over the range  $x = 0$  to  $x = l$ :

$$c_0 \int_0^l \cos(m+1/2) \frac{\pi}{l} x dx = \int_0^l K_n \cos(m+1/2) \frac{\pi}{l} x \cos(n+1/2) \frac{\pi}{l} x dx \quad (5)$$

The right side of eq. (5) is equal to 0 for all values of  $m$  not equal to  $n$ . Setting  $m = n$  and integrating eq. (5):

$$\frac{c_0 l}{(n+1/2)\pi} \sin\left\{(n+1/2) \frac{\pi x}{l}\right\} \Big|_0^l = \frac{K_n l}{(n+1/2)\pi} \left[ \frac{1}{2} (n+1/2) \frac{\pi x}{l} + \frac{1}{4} \sin\left(2(n+1/2) \frac{\pi x}{l}\right) \right] \Big|_0^l$$

Evaluating the limits and simplifying:

$$\frac{c_0 l}{\pi(n+1/2)} (-1)^n = K_n \frac{1}{2} l \quad \text{or} \quad K_n = \frac{4 c_0 (-1)^n}{\pi(2n+1)}$$

Substituting into eq. (4):

$$c = \sum_{n=0}^{\infty} \frac{4 c_0 (-1)^n}{\pi(2n+1)} e^{-(n+1/2)^2 \frac{\pi^2}{l^2} D t} \cos(n+1/2) \frac{\pi}{l} x \quad (6)$$

Equation (6) gives the concentration at any point throughout the emulsion from  $x = 0$  to  $x = l$  at any time  $t$ . The thiosulfate analysis of the film gives an average concentration of the film sample. An expression for the average concentration is obtained by integrating the concentra-

tion expression eq. (6) over the emulsion thickness and dividing by the thickness.

$$\bar{c} = \frac{1}{l} \int_0^l c \, dx$$

Substituting in eq. (6):

$$\begin{aligned} \bar{c} &= \frac{1}{l} \sum_{n=0}^{\infty} \frac{4 c_0 (-1)^n}{\pi (2n+1)} e^{-(n+1/2)^2 \frac{\pi^2}{l^2} D t} \int_0^l \cos(n+1/2) \frac{\pi}{l} x \, dx \\ &= \frac{1}{l} \sum_{n=0}^{\infty} \frac{4 c_0 (-1)^n}{\pi (2n+1)} e^{-(n+1/2)^2 \frac{\pi^2}{l^2} D t} \frac{l}{(-1)^n (n+1/2) \pi} \\ &= \sum_{n=0}^{\infty} \frac{8 c_0}{\pi^2 (2n+1)^2} e^{-(n+1/2)^2 \frac{\pi^2}{l^2} D t} \end{aligned}$$

By rearranging the terms in eq. (7) the diffusion constant can be determined:

$$\frac{\pi^2 \bar{c}}{8 c_0} = \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} e^{-(n+1/2)^2 \frac{\pi^2}{l^2} D t}$$

Expanding the series:

$$\begin{aligned} \frac{\pi^2 \bar{c}}{8 c_0} &= 1 \cdot e^{-\frac{\pi^2 t D}{4 l^2}} + \frac{1}{9} e^{-\frac{9 \pi^2 t D}{4 l^2}} + \frac{1}{25} e^{-\frac{25 \pi^2 t D}{4 l^2}} + \dots \\ &= e^{-\frac{\pi^2 t D}{4 l^2}} \left( 1 + \frac{1}{9} e^{-\frac{8 \pi^2 t D}{4 l^2}} + \frac{1}{25} e^{-\frac{24 \pi^2 t D}{4 l^2}} + \dots \right) \end{aligned}$$

Taking the natural logarithm of both sides:

$$\ln \frac{\pi^2 \bar{c}}{8 c_0} = -\frac{\pi^2 t D}{4 l^2} + \ln \left( 1 + \frac{1}{9} e^{-\frac{8 \pi^2 t D}{4 l^2}} + \frac{1}{25} e^{-\frac{24 \pi^2 t D}{4 l^2}} + \dots \right)$$

$$\text{Letting: } R = 1 + \frac{1}{9} e^{-\frac{8 \pi^2 t D}{4 l^2}} + \frac{1}{25} e^{-\frac{24 \pi^2 t D}{4 l^2}} + \dots$$

Then:

$$\begin{aligned} D &= -\frac{4 l^2}{\pi^2 t} \left( \ln \frac{\pi^2 \bar{c}}{8 c_0} - \ln R \right) \\ &= -\frac{4 l^2}{\pi^2 t} \ln \frac{\pi^2 \bar{c}}{8 c_0 R} \end{aligned}$$

D may be determined by an iterative technique, first setting  $R = 1$  and then alternately solving for D and then R until the desired accuracy is reached.

APPENDIX B

Fixer F-5			No Salt			Fixer F-5			No Salt		
Density 0.0			Temp. 25.5°C			Density 0.0			Temp. 24.2°C		
Time	Conc.	Thick.	Time	Conc.	Thick.	Time	Conc.	Thick.	Time	Conc.	Thick.
0 sec	1661. $\mu\text{g}/\text{in}^2$	-	0 sec	2018. $\mu\text{g}/\text{in}^2$	-	0 sec	2018. $\mu\text{g}/\text{in}^2$	-	0 sec	2018. $\mu\text{g}/\text{in}^2$	-
15 "	265.8 "	41.8 $\mu$	15 "	253.8 "	44.9 $\mu$	15 "	253.8 "	44.9 $\mu$	15 "	253.8 "	44.9 $\mu$
30 "	235.2 "	35.9 "	30 "	199.1 "	49.9 "	30 "	199.1 "	49.9 "	30 "	199.1 "	49.9 "
60 "	103.8 "	43.3 "	60 "	126.3 "	45.9 "	60 "	126.3 "	45.9 "	60 "	126.3 "	45.9 "
120 "	28.65 "	43.3 "	120 "	44.5 "	42.8 "	120 "	44.5 "	42.8 "	120 "	44.5 "	42.8 "
240 "	3.45 "	54.1 "	240 "	14.66 "	41.2 "	240 "	14.66 "	41.2 "	240 "	14.66 "	41.2 "
480 "	3.16 "	46.9 "	480 "	1.838 "	39.5 "	480 "	1.838 "	39.5 "	480 "	1.838 "	39.5 "
720 "	1.902 "	47.7 "	720 "	1.084 "	42.5 "	720 "	1.084 "	42.5 "	720 "	1.084 "	42.5 "

Fixer F-5			No Salt			Fixer F-5 2x Hard			No Salt		
Density 0.0			Temp. 33.0°C			Density 0.0			Temp. 24.5°C		
Time	Conc.	Thick.	Time	Conc.	Thick.	Time	Conc.	Thick.	Time	Conc.	Thick.
0 sec	1820. $\mu\text{g}/\text{in}^2$	-	0 sec	1529. $\mu\text{g}/\text{in}^2$	-	0 sec	1529. $\mu\text{g}/\text{in}^2$	-	0 sec	1529. $\mu\text{g}/\text{in}^2$	-
15 "	184.8 "	48.3 $\mu$	15 "	307.9 "	32.0 $\mu$	15 "	307.9 "	32.0 $\mu$	15 "	307.9 "	32.0 $\mu$
30 "	172.7 "	44.6 "	30 "	261.9 "	37.1 "	30 "	261.9 "	37.1 "	30 "	261.9 "	37.1 "
60 "	83.22 "	49.0 "	60 "	168.7 "	31.4 "	60 "	168.7 "	31.4 "	60 "	168.7 "	31.4 "
120 "	24.20 "	56.7 "	120 "	85.96 "	34.4 "	120 "	85.96 "	34.4 "	120 "	85.96 "	34.4 "
240 "	6.94 "	55.5 "	240 "	12.27 "	34.4 "	240 "	12.27 "	34.4 "	240 "	12.27 "	34.4 "
480 "	2.469 "	54.2 "	480 "	4.108 "	34.3 "	480 "	4.108 "	34.3 "	480 "	4.108 "	34.3 "
720 "	1.334 "	49.2 "	720 "	2.203 "	36.2 "	720 "	2.203 "	36.2 "	720 "	2.203 "	36.2 "

Fixer F-24                      No Salt  
 Density 0.0    Temp. 24.5°C  
 Time            Conc.            Thick.  
 0 sec 1369. µg/in<sup>2</sup>    -  
 15 "        10.84 "        62.7 µ  
 30 "        1.169"        65.2 "     
 60 "        0.303"        68.2 "     
 120 "       0.057"        66.3 "   

Fixer SH-1 & F-24    No Salt  
 Density 0.0    Temp. 25.0°C  
 Time            Conc.            Thick.  
 0 sec 1161. µg/in<sup>2</sup>    -  
 15 "        6.05 "        41.8 µ  
 30 "        3.04 "        40.8 "     
 60 "        0.001"        40.9 "     
 120 "       1.274"        41.0 "     
 240 "       0.071"        41.4 "     
 480 "       0.020"        41.8 "   

Fixer F-5                              Salt  
 Density 0.0    Temp. 26.0°C  
 Time            Conc.            Thick.  
 0 sec 1707. µg/in<sup>2</sup>    -  
 15 "        30.79 "        37.3 µ  
 30 "        3.96 "        39.8 "     
 60 "        0.180"        42.6 "     
 120 "       0.059"        42.8 "     
 240 "       0.055"        44.2 "     
 480 "       0.042"        45.6 "     
 720 "       0.077"        46.9 "   

Fixer F-5                              Salt  
 Density 1.0    Temp. 24.5°C  
 Time            Conc.            Thick.  
 0 sec 1757. µg/in<sup>2</sup>    -  
 15 "        30.78 "        38.5 µ  
 30 "        2.061"        39.0 "     
 60 "        0.071"        44.3 "     
 120 "       0.165"        42.6 "     
 240 "       0.055"        44.6 "     
 480 "       0.159"        46.5 "     
 720 "       0.007"        46.5 "



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