

INSTRUCTIONS FOR USING THE CREATECH PERMEOMETER MODEL 210T
FOR MEASURING OXYGEN PERMEABILITY OF CONTACT LENS MATERIALS

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During the past several years the procedure for measuring oxygen permeability of contact lens materials by means of the CREATECH PERMEOMETER MODEL 210T has remained unchanged but the method of data analysis has changed. The change has been made necessary by the development of contact lens materials with very high oxygen permeability. There are several experimental procedures, depending upon whether the material is a hydrogel or a rigid gas permeable material (RGP). There is also a difference in the form of the polarographic sensor depending upon whether the sample is flat or in the form of a contact lens.

HYDROGELS

Hydrogels contain water in the form of a saline solution therefore there is no need to add any material between the sample and the cathode. A hydrogel sample can be placed directly on the gold cathode. Although most hydrogel samples are in the form of a contact lens it is best to press the contact lens onto a flat cathode. For this purpose the small end of the vertical tube in the cell holder is pressed against the lens after the lens is placed on the cathode with the concave side up. A piece of nylon mesh stretched tightly across the end of the tube and held in place with thread wound into the groove will help hold the lens in place without restricting the movement of oxygen to the lens surface. The nylon mesh is taken from a woman's nylon stocking.

Hydrogel lenses can be placed on a curved surface sensor with the concave side down and held in place with the nylon mesh as described above. This procedure requires careful adjustment of the downward force applied by the nylon mesh to the apex of the lens. In the case of the lens on the flat sensor the force is only on the edge. For a curved sensor the nylon mesh applies a force at the apex.

RGP LENSES AND FLATS

If RGP materials are cut into the form of flat disks the permeability can be measured on the flat sensor. If the sample of RGP material is in the form of a lens then it must be measured on a curved surface sensor of about the same curvature as the base curvature of the lens. If the mismatch in curvature is greater than about 0.1 mm the RGP lens will be cracked, particularly if the lens is thin.

All RGP samples, either flats or lenses, need a piece of wet paper between the sample and the sensor. A square of cigarette paper (light or medium weight) about 1-1/2 cm on a side should be placed on the sensor and then a few drops of unpreserved saline should be dropped onto the center of the paper. The sample is then placed on the wet paper. The fit of the sample to the sensor should then be investigated with a magnifying glass to ensure that there are no bubbles of air under the sample.

METHODS OF DATA ANALYSIS

The polarographic single chamber procedure for measuring oxygen permeability of contact lens materials was developed in the days when HEMA and CAB were typical contact materials. The Dk of these materials was less than

10×10^{-11} (cm²/sec)(ml O₂ /ml x mm Hg). Now materials are available with Dk of 100 and above. A new method of data analysis is required. Two

improvements in data analysis were made. First the method was changed from measurement on one sample to a requirement that the measurement be made on a series of samples of the same material but different thickness. This is recommended for both hydrogel and RGP materials of all permeabilities but is an absolute requirement for RGP materials of D_k over 20.

The second improvement was the use of an edge effect correction. This effect is caused by the movement of oxygen from the area beyond the cathode project area on the upper surface of the sample. This correction is not yet in general use. Fortunately it can be applied to the final calculated D_k by simply multiplying the final result by a factor. The graph giving the factor appears as Figure 6 in the paper by Fatt, Rasson, and Melpolder, a copy of which is enclosed. The correction for edge effect if used should clearly be stated in any statement of a D_k value.

GENERAL PROCEDURE

The following instructions give the procedure for making the measurement at 35°C or any temperature above room temperature. If measurements near room temperature are desired it is essential to keep the polarographic cell in a box at or near 100% relative humidity. Also, it is always desirable to monitor the frame temperature of the polarographic cell. A simple but useful temperature and humidity controlled box can be constructed from a picnic cold box and a temperature controller from Oven Industries Inc., Box 229, Hempt Road, Mechanicsburg, PA 17055, Tel.(717) 766-0721. Model 5C5-335 with a probe for the 68 to 122°F temperature range is an optimum arrangement. The cost is about \$200. The Model 5C5-335 controller will both monitor and control box temperature to 1°F, about 1/2°C.

Note that the Permeometer will read cell temperature and will record cell temperature if connected to a suitable strip chart recorder. The measurement procedure should preferably begin the night before measurements are to be made. Alternatively the procedure can be started in the early morning for an afternoon measuring session.

First be sure that the Permeometer power switch is in the OFF position. Then connect the power cord to a 110-120v, 60 Hz, AC power source. Leave the power switch in the OFF position and carefully insert the connector on the cell cable into either A or B female connectors at the lower right hand side of the Permeometer panel. It will be assumed that INPUT A will be used in the procedure directions that follow. Either INPUT A or INPUT B can be used or two cells can be used simultaneously if desired. Choice of readout is made by the CELL SELECT switch. When two cells are connected to the Permeometer they are both always connected to the Permeometer circuit. The CELL SELECT switch selects only cell readout.

Line the bottom of the temperature controlled box with paper towels saturated with distilled water. Place the polarographic cell in its frame and put the entire assembly in the box. Also place in the box all of the samples that will be measured during the measurement session together with a supply of nonpreserved saline (Unisol or its equivalent is satisfactory). Insert the controller sensor end into a hole drilled for it in the upper arm of the frame. Close the box as tightly as possible, set the controller to 95°F (35°C) and allow the system to come to temperature equilibrium. At least four hours later the permeability measurements can begin.

Before turning the Permeometer power switch to the ON position remove the cell from the temperature controlled box and clean the electrode surface with a small wad of Duraglit or equivalent silver polishing wadding.

Duraglit is a British product made by Reckitt Household Products, Reckitt House, Hull, ENGLAND. Then wash the cell surface with warm saline from the saline container in the box. Wipe the surface of the cell dry with Kleenex tissue or equivalent. The Duraglit cleaning process is done on a daily basis only. The cell surface need not be cleaned between each measurement.

All operations that involve cleaning or placing samples on the electrode surface can best be done after the cell is removed from the frame and placed in a small instrument makers table vise. Masking tape should cover the jaws of the vise to avoid heat transfer from the warm cell to the cold metal jaws of the vise. It is wise to remove the vertical cylinder from the frame before attempting to remove the cell. This avoids the possibility of damaging the tightly stretched nylon mesh covering the bottom of the cylinder.

Flat Sample of Gas Permeable Hard Contact Lens Material

Place a drop warm saline solution on the center of the sensor surface. Place a piece (1/2" x 1/2") of Rizla Medium Weight cigarette paper on the cell surface so it absorbs the warm saline previously placed there. Add another drop of warm saline to the top surface of the paper. Place the flat sample on the saline-saturated paper. Return the cell to the frame and tighten the screw that holds the cell in the frame. Place the vertical cylinder in the frame with the small end (covered by the tightly stretched nylon mesh) down and push it gently on to the sample. Tighten the screw that holds the vertical cylinder in place while gently pushing down on the cylinder. Run a cotton-tipped swab down the inside of the vertical cylinder to remove any saline that might have wetted the top surface of the sample. Place a plug of tissue paper in the top of the vertical tube to prevent any condensate from the underside of the box lid dropping onto the sample.

Place the frame and the cell in the box. Put the sensor of the temperature controller into the hole on the top arm of the frame. Set CELL SELECT switch to the OFFSET position for the cell being used, cell A in this example. Set the OFFSET so that the CURRENT LCD shows zero reading. Return the CELL SELECT switch to A position.

Set the RANGE switch to give three digits on the CURRENT LCD. If a recorder is used set OUTPUT dial so that the recorder pen is near the top of its scale. The recorder is used only to show that current reading has stabilized. The current value needed in calculation of the permeability is taken from the CURRENT LCD indicator.

PERMEABILITY MEASUREMENT BASED ON A SINGLE SAMPLE

When the current and temperature readings are stable record both values. The time for current stabilization depends on the permeability of the material and the thickness of the sample. The time may range from five to 30 minutes. The current recorded at this point is called the "gross current". The calculation of oxygen transmissibility is made as follows.

1) Subtract 0.06 uA from the stable current reading. This is the "dark current" and represents the amount of current flowing through the cell when no oxygen is reaching the cathode. It was determined by using a glass plate instead of a oxygen permeable sample. After subtraction of 0.06 uA the current that remains is called the "net" current.

2) Multiply the net current by 3.0×10^{-9} . The 3.0×10^{-9} quantity is the cell constant for a flat cathode that is 4.0 mm in diameter and with air at

the exposed surface of the sample. The derivation of the cell constant is given in Appendix I. After the multiplication of the net current by the cell constant the result will be the total transmissibility of the sample and the saline-saturated cigarette paper in series. The total transmissibility is symbolized as $(Dk/L)_{Tot}$

3) Take the reciprocal of $(Dk/L)_{Tot}$ to give $(L/Dk)_{Tot}$.

4) Subtract 2.7×10^7 from $(L/Dk)_{Tot}$. The 2.7×10^7 term is $(L/Dk)_p$. This is the best average value for the reciprocal of the oxygen transmissibility of saline-saturated cigarette paper.

5) The result from Step 4 above is $(L/Dk)_{Sample}$. Take the reciprocal of this to get $(Dk/L)_{Sample}$. This is the oxygen transmissibility of the sample.

6) Multiply $(Dk/L)_{Sample}$ by thickness of the sample in centimeters. This will give oxygen permeability of the sample material and will be in the units (cm^2/sec) $(ml O_2/ml \times mm Hg)$.

SAMPLE CALCULATION USING THE GAS PERMEABLE HARD LENS DATA IN TABLE I

Gross current observed is 1.87 uA.

Subtract 0.06 uA to give 1.81 uA of net current.

Multiply net current by 3.0×10^{-9} to give 5.43×10^{-9} .

Take reciprocal of 5.43×10^{-9} to give 1.84×10^8 .

Subtract the reciprocal of paper transmissibility to give $1.84 \times 10^8 - 2.7 \times 10^7 = 1.57 \times 10^8$.

Take the reciprocal of 1.57×10^8 to give 6.37×10^{-9} . This is the transmissibility of the sample.

Multiply the transmissibility by the sample thickness, shown to be 0.0264 cm in the Table. The resultant oxygen permeability (Dk) is 16.8×10^{-11} . A somewhat different procedure for high permeability hard materials is given in a later section.

Measurement on a Hydrogel Flat Disc

The cell, frame, samples and solution should be allowed to come to temperature equilibrium in the temperature controlled box for at least four hours. The hydrogel sample should be immersed in an appropriate nonpreserved saline solution. Preserved saline solutions may contain mercury compounds that will interfere with the polarographic electrochemical reduction of oxygen at the cathode. The mercury compound may also attack the silver anode. After temperature equilibrium is reached the cell should be removed from the box and its electrode surfaces cleaned with Duraglit or equivalent just as was done for the gas permeable hard sample.

After the cell surface has been cleaned and then washed with warm saline a drop of warm saline is placed on the center of the electrode surface. The flat sample of hydrogel is then placed directly on the cell surface, no cigarette paper is used. The cell is placed in the frame and the cylinder with nylon mesh on its small end is placed in the frame with the small end down. The cylinder is pressed down gently and then the set screw is tightened. The set screws for both the cell and the vertical tube should now be tight. A cotton-tipped swab is then touched to the top of the

sample through the central hole in the vertical tube to remove any excess saline. A plug of tissue paper is placed in the tube at its top and the assembly is placed in the temperature controlled box. It is essential that the box be at or near 100% relative humidity. If the humidity is below 90% the hydrogel sample will dry out very quickly. A small humidity gauge in the box will help monitor relative humidity to ensure that it is in the 90-100% range. When cell current and temperature are stable the current reading is recorded. The dark current of 0.06 uA is subtracted from the observed reading to give the net current. The net current is multiplied by 3.0×10^{-9} to give the transmissibility of the sample directly. The thickness of the sample, as measured by a Rehder ET Electronic Thickness Gauge or equivalent is then converted to centimeters. The transmissibility when multiplied by the thickness in centimeters is the permeability of the sample material.

Measurement on Hydrogel Contact Lenses

The flat surface cell is prepared as was done for hydrogel flats. There are two ways to place a hydrogel lens on the flat surface cell. One method is to place the lens directly on a drop of saline previously put on the center of the cathode. The lens is placed with concave side up. The periphery of the lens should be in a horizontal plane. This kind of placement of the lens on the cathode is suitable for thick lenses, in the range 0.15 mm to 0.40 mm. Even with these lenses trial and error is required to place the lens in a level and centered position on the cathode. Capillary forces tend to pull the lens down on one side. After the lens is placed on the center and is level then the mesh-covered tube is lowered onto the lens and gently pressed down while the set screw is tightened. A cotton-tipped swab is touched to the top surface of the lens through the tube to remove excess saline. A wad of tissue paper is placed in the top of the tube to prevent condensate from falling into the tube.

The second method of placing a hydrogel contact lens in the cell is to drape it over the mesh on the end of the vertical tube. This method is used for thin hydrogel lenses that will not keep their shape if placed apex down on a drop of saline on the cathode. A thin hydrogel lens can be smoothed over the mesh-covered tube so that it is free of wrinkles. The tube is then placed in the frame and pressed down onto a drop of saline that had been previously placed on the center of the cathode. The calculation of transmissibility and permeability for the hydrogel lens is made in the same manner as for the hydrogel flat sample.

SAMPLE CALCULATION ON A HYDROGEL LENS IN THE ATTACHED TABLE I

A hydrogel flat and a hydrogel lens are treated in the same way. The sample calculation is made on a Bausch & Lomb Sofspin hydrogel lens. Gross current observed was 3.27 uA. Subtracting the dark current of 0.06 uA gives net current as 3.21 uA. Multiplying net current by the cell constant gives 9.6×10^{-9} as the transmissibility of the sample. The thickness of the sample is 0.0064 cm. This is multiplied by the transmissibility to give 6.2×10^{-11} as the permeability of the sample.

TABLE I

DATA FOR EXAMPLE CALCULATIONS OF OXYGEN TRANSMISSIBILITY AND PERMEABILITY
Temperature 35°C

Sample	Center Thickness	Gross Current	Net Current	Oxygen Transmissibility*	Oxygen
Permeability**	mm	microamps	micoramps		
Gas permeable hard lens 11	0.264	1.87	1.81	6.4×10^{-9}	16.8×10^{-11}
Hydrogel lens	0.064	3.27	3.21	9.6	6.2

* Units of transmissibility are (cm/sec)(ml O₂/ml x mm Hg)

** Units of permeability are (cm²/sec)(ml O₂/ml x mm Hg)

CALCULATIONAL PROCEDURE WHEN PERMEABILITY IS HIGH (ABOVE 20)

When the permeability of a hydrogel or gas permeable hard material is very high, over $Dk = 50 \times 10^{-11}$ then boundary layer effects may have an important influence on the permeability calculated from data collected from the polarographic cell. In the case of a hydrogel lens or flat sample the boundary layer is water squeezed out of the sample or it may be the partially dry thin surface layer on the hydrogel. In the case of a gas permeable hard flat sample or lens the boundary layer is the saline-saturated cigarette paper between the sample and the polarographic cathode. There may also be other boundary layer effects on hard materials but these effects are not yet fully understood. No matter what the source of the boundary layer effects the procedure given below will yield a true permeability independent of all boundary layer effects.

Boundary layer effects can be removed from the calculation of permeability by making a series of measurements on the same material but different sample thickness. For each sample the total Dk/L is calculated by multiplying the observed net current by the cell constant. This is called the total transmissibility, $(Dk/L)_{Tot}$, because it includes the sample Dk/L and boundary effects. Take the reciprocal of $(Dk/L)_{Tot}$ to give $(L/Dk)_{Tot}$. Plot $(L/Dk)_{Tot}$ on the vertical axis of a graph with sample thickness in cm on the horizontal axis. The slope of the straight line fitted to the points is $(1/Dk)$ of the material. The reciprocal of the slope is the true Dk of the material without any influence of boundary layers from any source.

A graph showing this kind of plot for 14 gas permeable hard materials is attached. Table II gives the calculated permeabilities of the materials together with transmissibility of lenses 0.10, 0.15, and 0.20 mm thick.

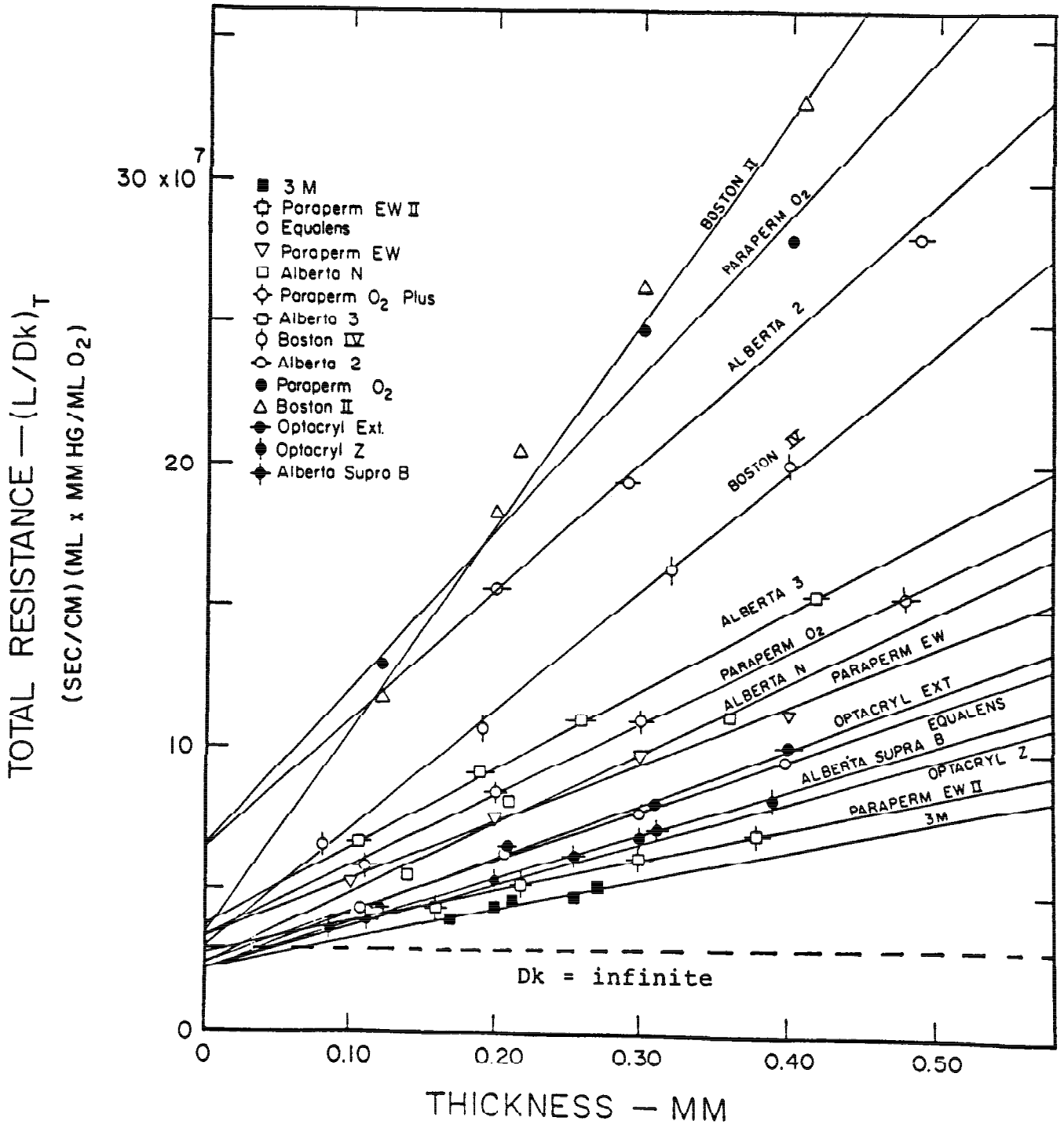


FIGURE 1

TABLE II

Oxygen Permeability (Dk) at 35° for 14 lens materials shown in Figure 1. Oxygen transmissibility for lenses made of these materials. Lens assumed to have uniform thickness as shown in the column heading below.

Material	Permeability* (Dk)	Transmissibility** (Dk/L)		
		Lens Thickness in mm		
		0.10	0.15	0.20
Alberta 2	22 x 10 ⁻¹¹	22 x 10 ⁻⁹	14.7 x 10 ⁻⁹	11 x 10 ⁻⁹
Alberta 3	36	36	24	18
Alberta N	40	40	26.7	20
Alberta Supra B	66	66	44	33
Boston II	14	14	9.3	7
Boston IV	24	24	16	12
Equalens	55	55	36.7	27.5
Paraperm 02	18	18	12	9
Paraperm 02 Plus	39	39	26	19.5
Paraperm EW	49	49	32.7	24.3
Paraperm EW II	92	92	61.3	46
3M	95	95	63.3	47.5
Optacryl EXT	54	54	36	27
Optacryl Z	67	67	44.7	33.5

* Units of transmissibility are (cm/sec)(ml O₂/ml x mm Hg)

** Units of permeability are (cm²/sec)(ml O₂/ml x mm Hg)

APPENDIX I

DERIVATION OF THE CELL CONSTANT EQUATION

Fick's law of diffusion states,

$$J = A(Dk/L) (P_1 - P_2) \quad (1A)$$

Faraday's law of current flow due to an electrochemical reaction states,

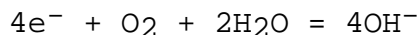
$$i = nFJ \quad (2A)$$

Since J is common to both equations we can combine them to give,

$$\text{Current} = i = (Dk/L) A N F P_{O_2} \quad (3A)$$

where (Dk/L) is the transmissibility of the material on the polarographic cell (this transmissibility includes boundary layer effects such as water squeezed out of the hydrogel or saline saturated cigarette paper), A is the area of the cathode (the sample is assumed to be very much larger than the cathode), N is the number of electrons needed to reduce a mole of oxygen to hydroxyl ions, F is the Faraday (a physical constant), and P_{O_2} is the oxygen tension on the open surface of the sample. The oxygen tension at the sample surface in contact with the cathode is believed to be zero.

The electrochemical reaction at the cathode is,



therefore N is 4 in equation 3A.

The Faraday constant is 96,500 amp sec/mole electron.

Equation 3A can be rearranged to read,

$$(Dk/L) = \text{Current}/A N F P_{O_2} \quad (4A)$$

The area A must be in square centimeters. N is taken as 4 mole electrons/mole even though there is some debate as to whether or not all of the oxygen is reduced by the 4 electron pathway. P_{O_2} will be taken as 155 mm Hg. This is the approximate oxygen tension in air at sea level. Obviously the true oxygen tension will depend upon the elevation of the laboratory, the weather, and conditions in the box where the polarographic reaction is taking place. The use of 155 mm Hg for the oxygen tension is only an approximation but is believed to be adequate in view of the other uncertainties in the measurement procedure, such as cathode area, sample thickness, water content of hydrogels, etc. The user can refine the cell constant that will be calculated here by using a local value of oxygen tension.

The cell constant will be calculated for a cathode 4.0 mm in diameter. The area of the cathode is 0.1256 cm². If another cell is used the area term can be modified accordingly.

$$(Dk/L) = \frac{\text{Current, amps} \times 10^{-6} \text{ microamps/amps} \times 22,400 \text{ cm}^3/\text{mole}}{0.1256 \text{ cm}^2 \times 4 \text{ mole electrons/mole} \times 96,500 \text{ amp sec/mole electron} \times 155 \text{ mm Hg}}$$

$$(Dk/L) = 3.0 \times 10^{-9} \times \text{current in microamps}$$

The units of (Dk/L) in the above equation will be (cm³/cm² x sec x mm Hg). This can be reduced to (cm/sec x mm Hg). If we multiply numerator and denominator by cm³ we obtain (cm⁶cm⁵ x sec x mm Hg). Since we know that D is normally given units of cm²/sec and k is ml O₂/ml x mm Hg and L is chosen in cm we can identify the units as (cm/sec)(ml O₂/ml x mm Hg). These are the units of transmissibility now in general use in the contact lens industry. When transmissibility is multiplied by thickness in centimeters the units of permeability become (cm²/sec)(ml O₂/ml x mm Hg).

ADDENDUM

Since the preparation of the enclosed Instruction Manual for using the Createch Permeometer, Model 210T, several developments worth mentioning have taken place in permeability measurement technology.

First is the issuance of an International Standards Organization (ISO) Standard for Determination of Oxygen Permeability and Transmissibility of Contact Lenses. This is ISO/DIS 9913.

The second development is the description by Weissman and Fatt of a method for measuring stacked hydrogel lenses when lenses of different thickness are not available. A reprint of their paper is enclosed.

The Contact Lens Association of Ophthalmologists (CLAO) has published an update of their *CLAO Guide to Basic Science and Clinical Practice* that includes a chapter on oxygen transmission through contact lenses. A copy of that chapter is enclosed.

The ISO Standard ISO/DIS 9913 recommends an edge effect correction and gives the equations that allow that correction to be made. Copies of the publication on which that correction is based are enclosed.

The ISO Standard 9913 gives the equation for the linear regression line when permeability (Dk) is calculated from measurements on lenses of different thickness, but the same material. They do not give an example of this calculation nor do they give a procedure for arriving at the statistical validity of the regression line and the permeability calculated from the slope of the regression line. An example of this calculation is appended to this addendum to demonstrate the entire procedure for calculating permeability of a material from measurements on four samples of different thickness of the same material. The example makes the calculation with and without the edge effect correction.

It is assumed that the user has available a calculator or computer that will give a least squares fit of a line to the four data points in the example.

Column 1 has the sample thickness in centimeters. This unit of length is used instead of millimeters because Dk and Dk/L are conventionally stated with centimeter units of length.

Column 2 has the steady state current readings from the Createch Permeometer.

In Column 3, the current readings of Column 2 are reduced by 0.1 microamp to take into account the current that flows in the absence of an oxygen flux.

The net current in microamps of Column 3 is multiplied by the cell constant to arrive at Dk/L in Column 4. In this case, the cell constant is:

$$2.60 \times 10^{-9} \left(\frac{cm}{sec} \right) \left(\frac{1}{microamps} \right) \frac{ml O_2}{ml \times mmHg}$$

Column 5 is the reciprocal of Column 4. At this point, the user can calculate the least square fitted line to L/Dk on the vertical axis and L on the horizontal axis. The calculation yields the slope of the line and the intercept of the line on the vertical axis. The calculator should also give the correlation coefficient (r).

In this case, the slope of the line (without edge effect correction) is 6.91×10^8 , the intercept on the vertical axis is 2.77×10^7 , and the correlation coefficient is 0.986737 .

The permeability of the material (Dk) is the reciprocal of the slope, that is $\frac{1}{6.91} \times 10^8$ or

$$145 \times 10^{-11} \left(\frac{cm^2}{sec} \right) \left(\frac{ml O_2}{ml \times mmHg} \right).$$

At this point, the user can calculate the statistical reliability of the calculated permeability value.

It is necessary first to calculate the quantity $\Sigma \left(\frac{L}{Dk} \right)^2$.

From statistics, we have:

$$\Sigma \left(\frac{L}{Dk} \right)^2 = \Sigma \left(\frac{L}{Dk} \right)^2 - \frac{\left(\Sigma \frac{L}{Dk} \right)^2}{N}$$

where N is the number of samples measured.

We also need ΣL^2 given by $\Sigma L^2 = \Sigma L^2 - \frac{(\Sigma L)^2}{N}$.

For the calculation without regard to edge effect, $\Sigma(\frac{L}{Dk})^2$ is given at the bottom of Column 9.

$(\Sigma\frac{L}{Dk})^2$ is given at the bottom of Column 5. N for this example is 4.

$\Sigma'(\frac{L}{Dk})^2$ is then $8.38 \times 10^{15} - \frac{(3.25 \times 10^{16})^2}{4}$. The result is 2.55×10^{14} .

Σ/L^2 is calculated from ΣL^2 given at the bottom of Column 8 as 3.07×10^{-3} and from $(\Sigma L)^2$ given at the bottom of Column 1 as 1.02×10^{-2} .

Σ/L^2 is then $3.07 \times 10^{-3} - \frac{(1.02 \times 10^{-2})^2}{4}$. The result is 5.20×10^{-4} .

The square of the statistical standard deviation of the slope of the regression line is given by:

$$SD^2 (slope) = \frac{(1-r^2)\Sigma'(\frac{L}{Dk})^2}{(N-2)\Sigma/L^2}$$

For this example $r = 0.986737$ so $r^2 = 0.973650$, $N = 4$, $\Sigma'(\frac{L}{Dk})^2 = 2.55 \times 10^{14}$, and

$$\Sigma/L^2 = 5.20 \times 10^{-4}.$$

$SD^2 (slope)$ is then 6.46×10^{15} .

Taking the square root gives $SD (slope) = 8.04 \times 10^7$.

The statistical standard deviation of the calculated permeability is $\frac{SD(\text{slope})}{(\text{slope})^2} = SD(Dk)$.

The standard deviation of Dk is then:

$$SD(Dk) = \frac{8.04 \times 10^7}{(6.91 \times 10^8)^2}$$

$$SD(DK) = 17 \times 10^{-11}$$

The standard deviation of Dk as a percentage of Dk is:

$$\left(\frac{17 \times 10^{-11}}{145 \times 10^{-11}}\right) \times 100 = 12\%$$

A 95 percent confidence limit requires two standard deviations, in this case 24 percent. Therefore, we can say with 95 percent confidence that the permeability lies within the range $145 \pm 35 \times 10^{-11}$.

These calculations can be repeated with the L/Dk data corrected for edge effect by using Column 10 in place of Column 9.

$$\Sigma\left(\frac{L}{Dk}\right)^2 = 10.83 \times 10^{15} - \frac{4.13 \times 10^{16}}{4} = 5.05 \times 10^{14}$$

The term Σ/L^2 remains the same.

We now need the slope, intercept, and correlation coefficient for L/Dk corrected for edge effect and plotted against L. The result is slope = 9.597×10^5 , intercept = 2.66×10^7 , and $r = 0.992546$. The permeability, Dk, is the reciprocal of the slope and is equal to 104×10^{-11} .

1	2	3	4	5	6	7	8	9	10
Sample Thickness (L_m)	Gross Current (microamps)	Net Current (microamps)	Dk/L	L/Dk	Flux Ratio (FR)	(L/Dk) x (FR)	L_m^2	(L/Dk) ² No Edge Effect	(L/Dk) ² With Edge Effect
0.0403	721	7.11	1.85×10^4	5.41×10^7	1.18	6.38×10^7	1.62×10^{-3}	2.92×10^{15}	4.07×10^{15}
0.0308	762	7.52	1.96	5.11	1.14	5.83	0.949	2.61	3.40
0.0200	933	9.23	2.40	4.17	1.10	4.59	0.400	1.74	2.11
0.0098	1166	11.56	3.00	3.33	1.06	3.53	0.095	1.11	1.25
$\Sigma L =$ 1.01×10^{-1}				$\Sigma \left(\frac{L}{Dk}\right) =$ 18.02×10^7		$\Sigma \left(\frac{L}{Dk}\right) =$ 20.33×10^7	$\Sigma L^2 =$ 3.07×10^{-3}	$\Sigma \left(\frac{L}{Dk}\right)^2 =$ 8.38×10^{15}	$\Sigma \left(\frac{L}{Dk}\right)^2 =$ 10.83×10^{15}
$(\Sigma L)^2 =$ 1.02×10^{-2}				$(\Sigma \frac{L}{Dk})^2 =$ 3.25×10^{16}		$(\Sigma \frac{L}{Dk})^2 =$ 4.13×10^{16}			