Selecting a Glove for Protection against Chemicals: Step 5 Interpreting and Using Permeation Data

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As you may recall from earlier, permeation data provide an indication of 1) “how soon” the chemical will pass through the glove and expose the user and 2) “how fast” the chemical will travel through the glove. The “how soon” is the breakthrough time (BT). The “how fast” is the permeation rate, also known as the steady-state permeation rate (SSPR). Both are important when selecting an appropriate glove for chemical protection. In addition, both should be considered together when selecting an appropriate glove and even when determining how long a glove should be used for. A new concept, area under-the-curve, will be presented here that should aid in the selection process.

Accounting for Use in the Workplace

Before we start, it is important to know that the conditions of actual worker use are quite different than laboratory test conditions. Based on past studies, the three primary factors that must be accounted for are batch/lot variability, temperature, and hand movement. The potential effects of each one of these factors are summarized below.

- Up to 2-fold differences in batch/lot permeation outcomes have been observed with glove products (Perkins and Pool, 1997).

- Most of the permeation tests are conducted at room temperature; however, hand/skin temperature is generally about 95°F (or 35°C). Up to a 2.5-fold decrease in BT and 3-fold increase in SSPR is possible with increased temperature (Klingner and Boeniger, 2002).

- Simulated hand movement has also been found to have an effect on chemical permeation. Up to a 30% decrease in BT has been observed with simulated movement. Likewise, up to an 80% increase in SSPR has been observed (Phalen and Wong, 2012).

With all these factors combined, we have a potential 10-fold decrease in chemical resistance going from laboratory testing to work-use conditions. Individually, we can expect to see a possible 5-fold decrease in the BT and up to a 5-fold increase in SSPR. Thus, a glove with a BT of 30 minutes may only provide up to 6 minutes of protection under work conditions. And once there is breakthrough, the rate of permeation may be much higher due to body heat and hand movement.

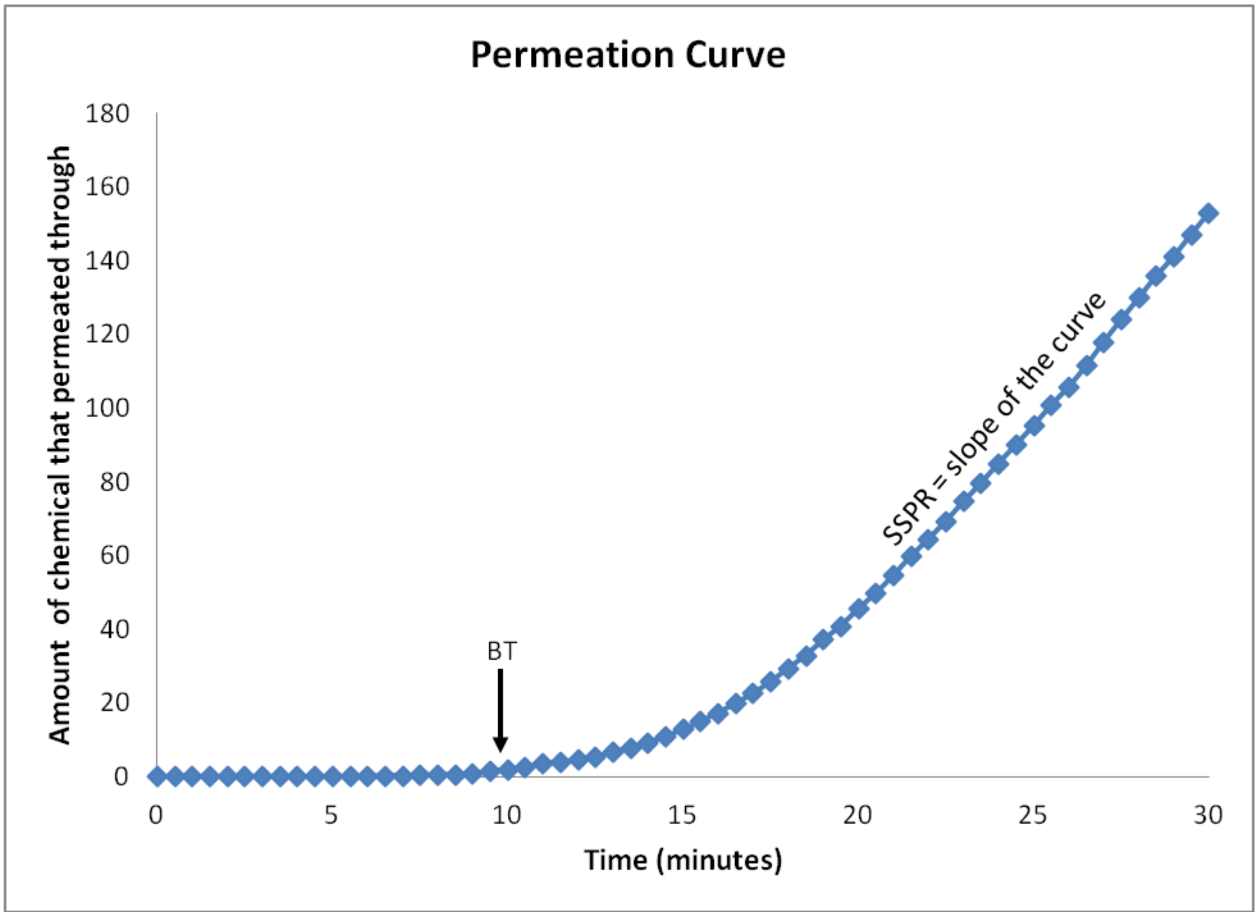
This information will not help with the selection of one product over another; however, it will help determine about how long a glove should be used for before it is discarded. In some cases, a thicker chemical resistant glove may be necessary, especially if the chemical is a severe irritant or has moderate toxicity.

The take home message here is that to account for product variability and work conditions it is best to:

1. divide the BT by 5; and
2. multiply the SSPR by 5.

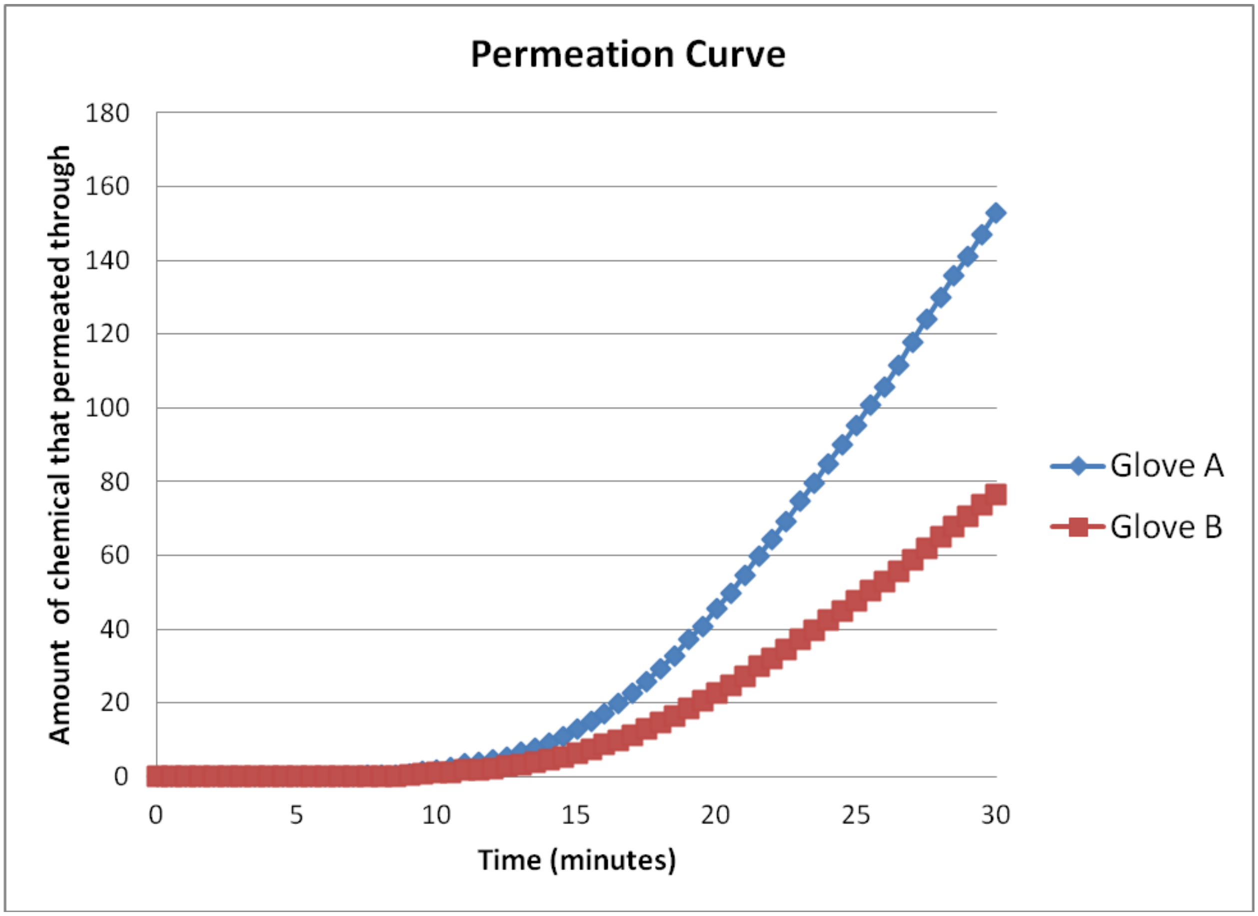
The Ideal Permeation Curve

In many cases we can assume the permeation follows an ideal permeation curve, which looks like the one below. This type of permeation curve is typical if the chemical does not degrade, dissolve, or otherwise significantly alter the glove material—the curve represents the molecular movement of the chemical through the material. The BT is the time when the chemical first breaks through the glove material and it is detected on the other side, which is about 10 minutes in the figure below. The SSPR is the steady-state rate of movement of the chemical through the glove material after breakthrough. The SSPR is the slope of the linear portion of the permeation curve, with units typically of a mass per surface area per time (e.g., $\mu g/cm^2/min$). The SSPR in the figure is about 10 $\mu g/cm^2/min$. In the linear region, for every 1 minute increase there is a 10 $\mu g/cm^2$ increase in the chemical passing through the material.



Calculating the Cumulative Permeation

The next diagram below shows permeation data for two different gloves with similar BTs, but different SSPRs. Notice that at the end of 30 minutes the cumulative amount of the chemical is about 150 units for Glove A and 75 units for Glove B. The cumulative amount for Glove A is about double that of Glove B. If glove use was about 30 minutes, then Glove B would be the obvious better choice.



The "estimated" cumulative amount after a given time (t) can be calculated using the following formula (Phalen and Wong, 2012).

$$\text{Cumulative Permeation} = (t - BT) \times SSPR$$

For Glove A, with a BT of 10 min and a SSPR of 10 µg/cm^2/min, the 30-minute cumulative permeation estimate is 200 µg/cm^2 (see calculation below).

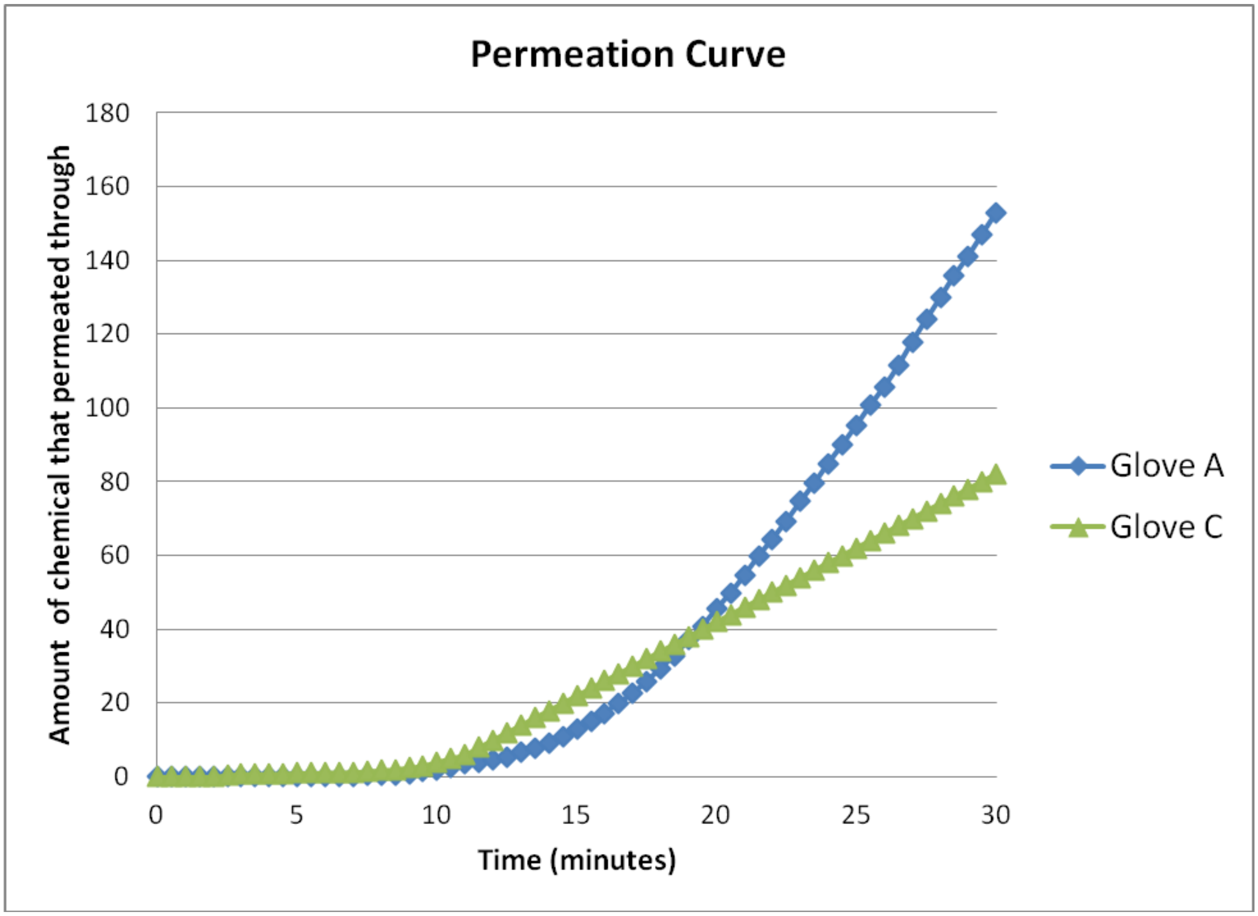
$$\begin{aligned}\text{Glove A Cumulative Permeation} &= (30\ \text{min} - 10\ \text{min}) \times 10\ \mu\text{g/cm}^2\text{/min} \\ &= 20\ \text{min} \times 10\ \mu\text{g/cm}^2\text{/min} \\ &= \mathbf{200\ \mu g/cm^2}\end{aligned}$$

For Glove B, with a BT of 10 min and a SSPR of 5 µg/cm^2/min, the 30-minute cumulative permeation estimate is 100 µg/cm^2 (see calculation below).

$$\begin{aligned}\text{Glove B Cumulative Permeation} &= (30\text{ min} - 10\text{ min}) \times 5\ \mu\text{g/cm}^2\text{/min} \\ &= 20\text{ min} \times 5\ \mu\text{g/cm}^2\text{/min} \\ &= \mathbf{100\ \mu g/cm^2}\end{aligned}$$

We can see that the estimates are a little higher than the actual permeation curve results, but often we will only have the BT and SSPR—the curves are rarely provided. The end result is still the same. Glove B is a better overall choice for a 30-minute exposure scenario.

Below is another example where the BT is much sooner for one glove (Glove C), but the SSPR is much lower. For Glove C, the BT is about 3 minutes and the SSPR is 2 µg/cm^2/min. Even though the BT is much sooner for Glove C, the cumulative permeation after 30 minutes is about half that of Glove A. Thus, for a 30-minute glove use period Glove C appears to be the better choice.



However, notice that the permeation curves (above) cross at about 18 minutes. If glove use was only going to be for a maximum of 15 minutes, then Glove A appears to be a slightly better choice, but not by much. In this scenario, the cumulative permeation calculations do not adequately address the permeation data. The 15-minute estimated cumulative permeation amounts are:

<u>50 μg/cm² for Glove A</u>

$$\text{Glove A Cumulative Permeation} = (15\text{ min} - 10\text{ min}) \times 10\ \mu\text{g/cm}^2/\text{min}$$
$$= 5\text{ min} \times 10\ \mu\text{g/cm}^2/\text{min}$$
$$= \mathbf{50\ \mu g/cm^2}$$

<u>24 μg/cm² for Glove C</u>

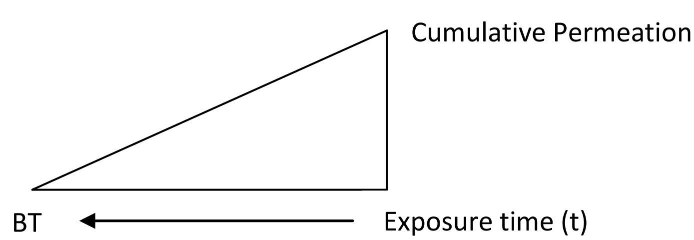
$$\text{Glove C Cumulative Permeation} = (15\text{ min} - 3\text{ min}) \times 2\ \mu\text{g/cm}^2/\text{min}$$
$$= 12\text{ min} \times 2\ \mu\text{g/cm}^2/\text{min}$$
$$= \mathbf{24\ \mu g/cm^2}$$

From the permeation curves, Glove A is the better choice for a 15-minute exposure period, but the cumulative permeation calculations show the opposite and the discrepancy is extreme. This discrepancy is because the estimated cumulative permeation does not take into account the lag time or rounded portion of the permeation curve. Thus, we need a better measure of cumulative amount to best represent potential worker exposures at given time periods when only being provided BT and SSPR data. This leads us to an improved measure called area under-the-curve or AUC, which is commonly used in toxicology to assess exposures (Phalen and Wong, 2012).

Area Under-the-Curve

A simplified calculation of the AUC is presented here, mainly because permeation curve data are often limited to the BT and SSPR. The curves or raw data are often not reported—only the BT and SSPR. Thus, we must assume a roughly triangular shape of the area under the curve, just past the BT. Fortunately, using a measure of area will give us a little better estimate of worker "exposure" than the previous cumulative permeation. The reasoning and justification for AUC is provided in an article by Phalen and Wong (2012) in the *Journal of Occupational and Environmental Hygiene*. For simplicity, it is best to illustrate how to calculate and use the AUC, rather than go into too much detail on the derivation. So, here we go.

If we assume a triangular shape, then the bottom of the triangle is the distance between the BT and final exposure time (t), and the height of the triangle is the estimated cumulative permeation, which we calculated earlier.



Using the formula for the area of a triangle the area will be 1/2 base times height. This can be worked into the formula below.

$$\text{AUC}(t) = 1/2 \times (t - \text{BT}) \times \text{Cumulative Permeation}$$

For Glove A, with a BT of 10 minutes, a SSPR of 10 µg/cm^2/min, and a cumulative permeation of 200 µg/cm^2 after 30 minutes, the AUC(30 min) can be calculated as:

$$\begin{aligned}\text{AUC(30 min)} \quad &= 1/2 \times (30\text{ min} - 10\text{ min}) \times 200\ \mu\text{g/cm}^2 \\ &= 1/2 \times 20\text{ min} \times 200\ \mu\text{g/cm}^2 \\ &= \mathbf{2{,}000\ min{\cdot}\mu g/cm^2}\end{aligned}$$

The result for Glove B is:

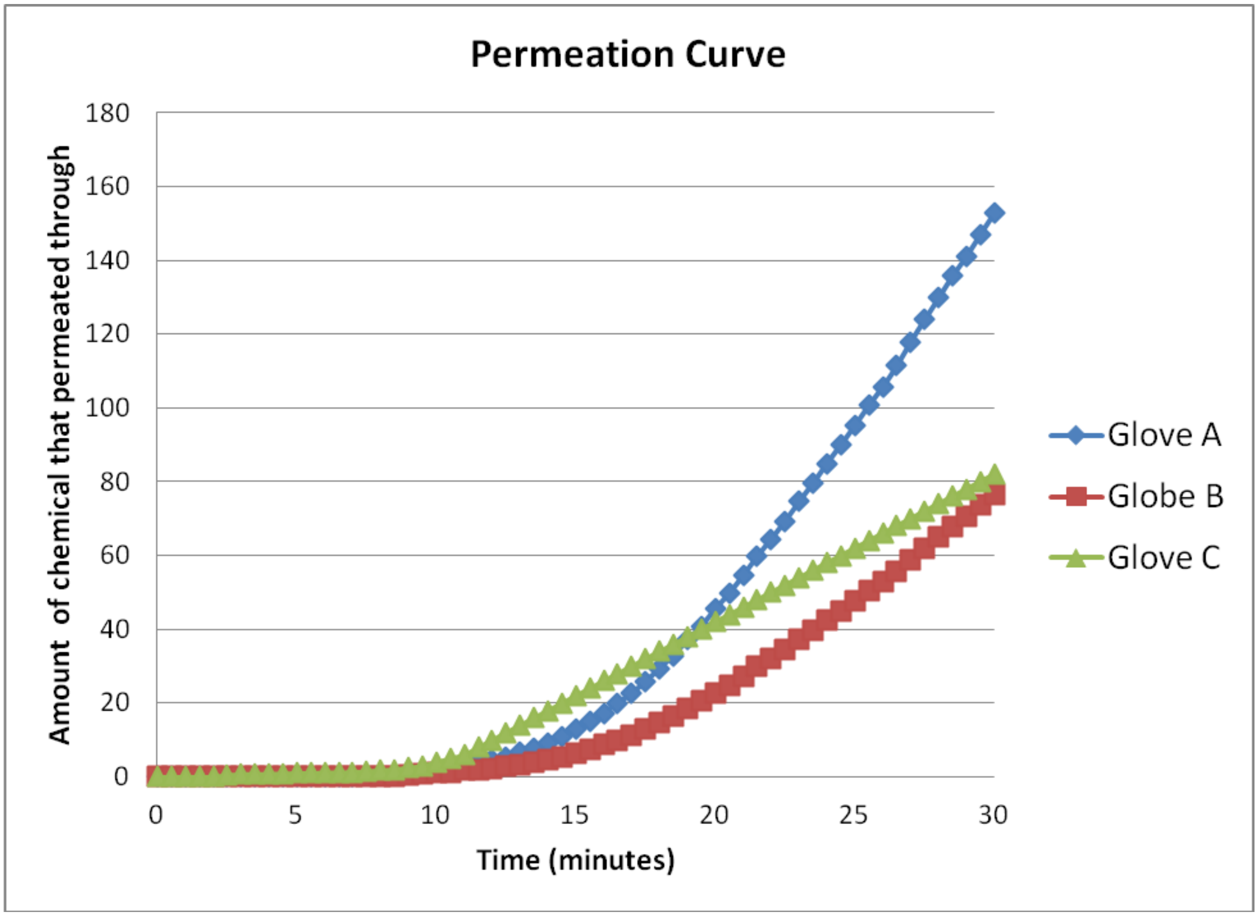
$$\begin{aligned}\text{AUC(30 min)} \quad &= 1/2 \times (30\text{ min} - 10\text{ min}) \times 100\ \mu\text{g/cm}^2 \\ &= 1/2 \times 20\text{ min} \times 100\ \mu\text{g/cm}^2 \\ &= \mathbf{1{,}000\ min{\cdot}\mu g/cm^2}\end{aligned}$$

This is consistent with the permeation curve data, showing that Glove B is a better choice for 30-minute exposure periods.

The result for Glove C, with an estimated 30-minute cumulative permeation of 54 µg/cm^2 is:

$$\begin{aligned}\text{AUC(30 min)} \quad &= 1/2 \times (30\text{ min} - 2\text{ min}) \times 54\ \mu\text{g/cm}^2 \\ &= 1/2 \times 28\text{ min} \times 54\ \mu\text{g/cm}^2 \\ &= \mathbf{756\ min{\cdot}\mu g/cm^2}\end{aligned}$$

This indicates that Glove C is the best overall choice for a 30-minute exposure period. However, the AUC(30 min) for Glove B is similar and the longer BT makes it a slightly better choice. Looking at the actual permeation curves for all three gloves (see below) shows how Glove B and Glove C appear to be much better choices over Glove A. The long lag time for Glove B accounts for the lower observed area under-the-curve than indicated in the AUC(30 min) estimate. Nevertheless, the estimates are close to each other.



Now it is time to test the 15-minute exposure scenario. From the permeation curves (above), Glove B should be the best choice, followed by Glove A. The calculated 15-minute cumulative permeation estimates for the gloves are:

- 50 µg/cm^2 for Glove A
- 25 µg/cm^2 for Glove B
- 24 µg/cm^2 for Glove C

The cumulative permeation estimates definitely do not work for this 15-minute scenario. Glove C is shown to be the better choice, when it is obviously the worst choice. Let us now calculate the AUC(15 min) for each glove.

For Glove A, the AUC(15 min) can be calculated as:

$$\begin{aligned} \text{AUC(15 min)} &= 1/2 \times (15\text{ min} - 10\text{ min}) \times 50\ \mu\text{g/cm}^2 \\ &= 1/2 \times 5\text{ min} \times 50\ \mu\text{g/cm}^2 \\ &= \mathbf{125\ min{\cdot}\mu g/cm^2} \end{aligned}$$

For Glove B, the AUC(15 min) is:

$$\begin{aligned} \text{AUC(15 min)} &= 1/2 \times (15\text{ min} - 10\text{ min}) \times 25\ \mu\text{g/cm}^2 \\ &= 1/2 \times 5\text{ min} \times 25\ \mu\text{g/cm}^2 \\ &= \mathbf{62.5\ min{\cdot}\mu g/cm^2} \end{aligned}$$

For Glove C, the AUC(15 min) is:

$$\begin{aligned} \text{AUC(15 min)} &= 1/2 \times (15\text{ min} - 3\text{ min}) \times 24\ \mu\text{g/cm}^2 \\ &= 1/2 \times 12\text{ min} \times 24\ \mu\text{g/cm}^2 \\ &= \mathbf{144\ min{\cdot}\mu g/cm^2} \end{aligned}$$

The AUC(15 min) calculations adequately predict the observed permeation curves showing Glove B as the best choice, followed by Glove A, and lastly Glove C. The short BT with Glove C is a real issue for short term exposures. Because the SSPR is very slow, Glove C is an okay alternative for longer exposures. However, a longer BT should always be desired. When the AUC data are close the longer BT should be a logical choice for increased worker protection and assurance. The overall best choice among the three gloves should be Glove B, for both the 15-minute and 30-minute exposure scenarios.

Conclusions

The AUC may not be the greatest method for evaluating the combined effects of BT and SSPR on chemical resistance, but it provides a more reliable estimate of potential exposures than cumulative permeation. The AUC also uses both the BT and SSPR to assess and model overall chemical resistance for a set time period. The steps are simple:

1. Calculate the estimated cumulative permeation from the BT, SSPR and exposure time (t). Cumulative Permeation = (t – BT) × SSPR

2. Calculate the AUC from the BT, exposure time (t) and cumulative permeation estimate. AUC(t) = 1/2 × (t – BT) × Cumulative Permeation

3. Select the glove choice with the lower AUC and longer BT, if the AUC values are similar.

Lastly, once a glove has been selected, it is important to account for work conditions when applying the BT and SSPR to protect workers. As a measure of safety, divide the BT by 5 and multiply the SSPR by 5. For ultimate protection it is best to select a glove with a BT much longer than the exposure period. For example, a BT five times longer than the projected use will provide a margin of safety.

References and Additional Reading:

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