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OF ADULT FEMALES OF THE HOUSE DUST
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THE CRITICAL EQUILIBRIUM ACTIVITY OF ADULT FEMALES OF THE HOUSE DUST MITE, Dermatophagoides farinae HUGHES

Dissertation

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School at The Ohio State University

by

David George Larson, B. A., M.S.

*****

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Approved by

Advisor

Academic Faculty of Entomology
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VITA

July 11, 1942.......................... Born - Sioux Falls, South Dakota

1964.......................... B. A., Concordia College, Moorhead, Minnesota

1964-1966.......................... Research Assistant, Department of Entomology and Applied Ecology, University of Delaware, Newark, Delaware

1966.......................... M. S., University of Delaware, Newark, Delaware

1966-1969.......................... Acarology Predoctoral Trainee, Acarology Laboratory, The Ohio State University, Columbus, Ohio

PUBLICATIONS


FIELDS OF STUDY

Major Field: Entomology

Studies in Acarine Water Balance. Professor G. W. Wharton
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INTRODUCTION

The net movement of water through arthropod integument at water vapor pressures below saturation is known to play a significant role in the water balance of many arthropods. The animal involved, the physiological state of the organism, and the ambient aqueous vapor activity has been found to determine whether the net movement of water is into or out of the organism where activity $a_v$ is:

$$a_v = \frac{r.h.\%}{100}$$

which varies from 0.0 to 1.0.

The influence of water vapor activity on the water content of arthropods has been thought to be comparable to the responses of non-living hygroscopic substances to water vapor activity. Such substances behave as follows (Knülle and Wharton, 1964):

1. The uptake of water vapor from the air varies according to the (vapor activity) of the air, and in the biological range, is only slightly influenced by temperature;
2. the amount of water taken up by hygroscopic substances until equilibrium is reached is greater at high than at low (activities);
3. sorption of water vapor always occurs when a hygroscopic substance that is in equilibrium with ambient conditions is transferred from a lower to a higher (activity) no matter how high the water content of the substance may be;
4. an equilibrium is established between the (vapor activity) of the air and the water content of the hygroscopic material; the higher the (vapor activity) the higher will be the water content of the hygroscopic substance.
Studies made of arthropod water balance indicate that dead arthropods do respond to water vapor activity in the same manner as non-living hygroscopic substances; however, studies of water balance made with living arthropods point out a significant difference in the response of these organisms to water vapor activity as compared to the response of hygroscopic substances. This difference is that below a certain critical activity living arthropods have been found incapable of effecting a net gain of water. Above this activity which has been termed the critical equilibrium activity (Wharton and Devine, 1968) and hereafter is designated as the CEA, a water gain occurs whenever an organism is transferred from a lower to a higher activity; but at activities below the CEA transferring organisms from lower to higher activities only results in a continuation of water loss until death by desiccation results and until static equilibrium with the environmental activity is reached.

The CEA has been determined for a number of arthropods and has been done at 25°C unless it is indicated otherwise. The CEA of the spiny rat mite, Laelaps echidnina (Berlese), at 26°C is near 0.90 (Wharton and Kanungo, 1962); in larvae of the yellow mealworm, Tenebrio molitor L., the CEA is at 0.88 (Mellanby, 1932); the sheep tick, Ixodes ricinus L., exhibits a net gain of water at an activity as low as 0.86 (Lees, 1964); the nymphs of the green-striped grasshopper, Chortophaga viridifasciata De Geer, has a CEA of 0.82 (Ludwig, 1937); the larvae of Dermacentor andersoni (Stiles), Dermacentor variabilis (Say), and Amblyomma cajennense (Fabricius) have a CEA between 0.80 and 0.85.
(Knüll, 1966); nymphs and adult females of Arenivaga sp. have a CEA of 0.825 (Edney, 1966); the grain mite, Acarus siro L., has a CEA of 0.71 (Knüll, 1965); the psocid Liposcelis knullei Broadhead, has a CEA of about 0.70 (Knüll and Spadafora, 1969); the larvae of the oriental rat flea, Xenopsylla cheopis (Roths.), has a CEA of 0.65 (Knüll, 1967b); the psocids, Liposcelis bostrychophilus Badonnel and Liposcelis rufus Broadhead, have a CEA of about 0.60 and 0.58 respectively (Knüll and Spadafora, 1969); and the prepupae of the rat flea, Xenopsylla brasiliensis Baker, has a CEA as low as 0.50 (Edney, 1947). The lowest CEA yet recorded is 0.45 for the firebrat, Thermobia domestica (Packard), at 21°C (Beamant et al., 1964).

Two different methods have been used to determine the CEA of arthropods (Wharton, 1963). In one method an organism or group of organisms of a particular instar and/or condition is enclosed in a relatively small air space in terms of the amount of water in the air compared to the amount of water in the organism. The water in the air and in the organism will come into equilibrium at approximately the CEA for the organism and instar exposed. Edney (1957) used this method for determining the CEA for the prepupae of X. brasiliensis. Another method has been to determine the lowest activity at which desiccated organisms maintain or gain weight by exposing them to a graded series of different activities where a change in weight reflects a change in the water mass in the organism. Starved desiccated animals are usually used in such determinations in order to prevent excretion, reproduction, or excess water in the digestive tract from influencing the water mass in the
organism. For the same reason the metabolism of the animal is kept as low as possible which is usually done by confining the animal. The study by Wharton and Kanungo (1962) is an example of this method used to determine the CEA for L. echidnina.

In a study of the exchange of tritiated water between L. echidnina and the surrounding air at equilibrium conditions (Wharton and Devine, 1968), net mass change, Δw, was considered to be the resultant of sorption less transpiration:

\[ Δw = S - T^* \]

where S is sorption and is proportional to the tritium concentration in counts per minute (CPM) and T* is transpiration and is proportional to the tritium content in CPM. At equilibrium conditions sorption and transpiration were found to proceed simultaneously, to be independent of each other and to be equal to each other.

A corresponding equation stating the relationship between the rate constants for mass change, sorption and transpiration is (Wharton and Devine, 1968):

\[ k_m = k_S - k_{T^*} \]

These constants may be expressed as follows:

\[ k_m = t^{-1} \ln \frac{m_t}{m_0} \]
\[ k_S = t^{-1} \ln \frac{S_t}{S_o} \]
\[ k_{T^*} = t^{-1} \ln \frac{T_t^*}{T_o^*} \]

where t equals time, subscript t equals mass, tritium concentration or tritium content at time t, and subscript o equals the original mass.
tritium concentration or tritium content. These rate constants were found to vary with change in vapor activity (Devine, 1969).

The house dust mite, *Dermatophagoides farinae* Hughes, 1961, has been implicated as a source of house dust allergen for better than 80 percent of the house dust sensitive patients tested (Mitchell et al., 1969). This mite is readily reared in an activity of 0.75, and what little else is known about the biology of this organism and its association with man has been summarized by Larson, Mitchell and Wharton (in press). The most recent revision of the genus (Fain, 1967) includes a treatment of all the described species, and Spieksma (1967) provides the only other information available on the biology of any other species of this genus.

The use of saturated salt solutions to establish desired activities has been a common practice (Winston and Bates, 1960). Various concentrations of aqueous solutions of sulfuric acid, potassium hydroxide and glycerol (Solomon, 1951; Newman, 1968) have also been used to establish desired activities. However, the responses of test organisms in activities established by various solutions have rarely been compared.

In this study the CEA for adult female *Dermatophagoides farinae* at 25°C is determined. A comparison of the net movement of water at activities established with aqueous solutions of glycerol and potassium hydroxide is made. A zero order and a first order model of water mass in the mites with change in activity are compared with the observed
values. The rate constants of water exchange as functions of the water vapor activity of the air are discussed.
MATERIALS AND METHODS

The mites used in this study were from stock cultures of *D. farinae* maintained in the Acarology Laboratory (Larson et al., in press). The culturing, standardization and testing of the mites was conducted at 25 ± 1°C in Scheibler desiccators in a BOD incubator where the desiccators were used as a closed air space in which to establish desired activities. The mites were cultured in a constant activity of 0.75 maintained with a saturated solution of sodium chloride (Winston and Bates, 1960) and were individually collected for testing with a number 00 brush from the lip of the culture vials or the culture medium. The mites in any one test were all taken from the same culture vial and were not fed for 48 hours before being tested.

The activities at which the mites were tested were established with various aqueous solutions of glycerol (Newman, 1968) and potassium hydroxide (Solomon, 1951). These solutions were prepared on the basis of weight percent concentrations where a given gram weight of glycerol or potassium hydroxide was brought up to 100 gms with distilled water. Fresh solutions were made for each exposure of mites to test activities.

A preliminary study was made of the survivorship of all instars of *D. farinae* to various activities ranging from 0.40 through 0.70 established by various aqueous solutions of glycerol. Four replications were made at each activity with dog food and 20 or more mites in each
replicate. How many mites were still alive at each activity was
determined at the end of 15 days.

Adult females were selected for a number of reasons as the instar
of D. farinae for which to determine the CEA. The female is the largest
instar, weighs the most, and is the easiest instar to pick out of a
culture. No attempt was made to select females of a uniform age.

The average dimensions of the idiosoma of the adult female are
418 x 362 µ (Fain, 1967), and this small size makes handling and weigh­
ing of individual mites difficult. This was solved by individually
caging the mites. The cage is cup-shaped with a hemispherical bottom
and is pressed out of aluminum foil with a die. A cover to the cage is
punched out of 400-mesh stainless steel screen with a paper punch. A
mite is placed in the cage bottom, screen placed in the top, and the
edge of the cup crimped over the screen with another die. The resulting
cage is 7 mm in diameter, 2 mm in depth, and has a volume of about
16 mm³. The mean empty weight of the cage is 8.39 ± .06 mg. There is
no difference in the weights of empty cages before and after exposure to
various activities less than 1.00.

The caged mites were weighed on a model G-2 Cahn Electrobalance
which has a sensitivity of 50 nanograms. The weighings were done on the
0.5 mg range of the balance by making scale stirrups so the cages could
be used as scale pans and by tareing off the majority of the cage weight.
This balance can be calibrated with class M weights to an absolute
weight tolerance of ± 0.27 µg. This calibration was rechecked daily
but was found to drift only when the scale went unused for more than
two days or was turned off. Reproducible weighings were consistently obtained with a tolerance of ± 0.1 μg at the rate of about one weighing per minute.

The point of beam balance which is at the null point of the balance meter was found to drift at the 0.5 mg range. Because of this, zero was rechecked after every third weighing. The three weights were not included in the data whenever the balance did not rezero when checked. The readjustment of zero proved necessary after about every fourth group of three weighings.

The caged mites were standardized by holding them 24 hours at an activity of 0.75 maintained with sodium chloride. This was followed by six hours of dehydration at an activity of 0.0 maintained by dried silica gel. The mites in the cages were then weighed.

After obtaining the initial balance reading, \( b_1 \), the cages were randomly assigned to one of the six desiccators used in each test. The mites were held 24 hours at the test activities and reweighed, \( b_{24} \). The order in which the six desiccators and cages in the six desiccators was reweighed was assigned at random. The change in weight for 24 hours \( \Delta w_{24} \) was determined by the following equation:

\[
\Delta w_{24} = 0.5(b_{24} - b_1)
\]

The multiplication by 0.5 was necessary because the weighings were done on the 0.5 mg range of the balance.

After the second weighing was made the cages were opened, and the mites were examined. The criterion used for a mite being alive was whether or not the mite moved when touched with a brush bristle. The
data for mites which were squashed in making the cage or were dead at the end of the test were not included in the results of the test.

The $\Delta W_{24}$ for standardized mites was determined for six activities 0.05 points apart ranging from 0.50 through 0.75 (Table 1). Each of the six activities was established with aqueous solutions of either glycerol or potassium hydroxide. The vapor pressure corresponding to each of the test activities is included in Table 1.

Table 1. - The weight percent concentrations of glycerol and potassium hydroxide for the activities tested with the corresponding aqueous vapor pressure at 25°C.

<table>
<thead>
<tr>
<th>$a_v$</th>
<th>wt. %</th>
<th>vapor pressure (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Glycerol</td>
<td>KOH</td>
</tr>
<tr>
<td>0.50</td>
<td>79.8</td>
<td>33.7</td>
</tr>
<tr>
<td>0.55</td>
<td>76.4</td>
<td>31.6</td>
</tr>
<tr>
<td>0.60</td>
<td>72.3</td>
<td>29.5</td>
</tr>
<tr>
<td>0.65</td>
<td>69.0</td>
<td>27.3</td>
</tr>
<tr>
<td>0.70</td>
<td>64.0</td>
<td>25.0</td>
</tr>
<tr>
<td>0.75</td>
<td>58.5</td>
<td>22.2</td>
</tr>
</tbody>
</table>

Considerable time was required for the caging and weighing of individual mites; therefore, only a limited number of mites could be efficiently handled during any one day. For this reason each test consisted of the exposure of eight mites per activity to three activities of both solutions or a total of 48 mites per period. The following
combinations of activities were tested: 0.50, 0.55 and 0.60; 0.60, 0.65 and 0.70; and 0.65, 0.70 and 0.75; and the data for repeated activities of each solution were pooled.

The regression coefficients for the glycerol and potassium hydroxide data were calculated and were subjected to an appropriate t-test of homogeneity with the null hypothesis that there was no difference between the data obtained from the two solutions. The data from the two solutions were then pooled.

The mean water mass of adult females in equilibrium with an activity of 0.75 was determined by dehydrating 28 mites to dry weight. The females were caged individually in cages of known weight, weighed, and reweighed after being held 15 days over dry silica gel. The mites were returned to redried silica gel and reweighed 24 hours later. Another 30 mites were set up in the same manner except for the dehydration to determine the mean weight of adult females.

Net mass change was assumed to follow either a zero order or a first order relationship with change in activity where a zero order model predicts an arithmetic change in mass with change in activity, and a first order model predicts an exponential change in mass with change in activity. The constants for zero and first order least squares regression line equations for the data were calculated with regression programs for a model 9100A Hewlett-Packard calculator.

The zero order equation for the mass of water in the mites, $m_a$, after 24 hours of exposure to a given activity, $a_v$, is:

$$ m_a = k a_v + m_z $$  \(1\)
where \( k \) is the slope and \( m_z \) is the intercept value of the zero order regression line at the activity of 0.0. Since \( m_a \) may also be stated:

\[
m_a = m_0 + w_{24}
\]  

(2)
equation 1 becomes:

\[
m_0 + \Delta w_{24} = k a_v + m_z
\]  

(3)
where \( m_0 \) is the mass of water in the mites at the end of six hours of dehydration at the activity of 0.0.

The value of \( m_0 \) was calculated by determining a zero order regression line equation for the values of \( \Delta w_{24} \), which gives the intercept value of the regression line at the activity (\( a_v \)) of zero. Dividing this intercept value by 24 hours gives the value of \( k \) when \( a_v = 0.0 \) for the following equation:

\[
m_t = k t + m_0
\]  

(4)
where \( m_t \) is the mass of water left in the mites at a given activity at the end of time \( t \) and \( m_0 \) is the original mass or the mass of water in the mites at time zero. Solving equation 4 for six hours gives the value of \( m_0 \).

The first order equation for the mass of water in the mites after 24 hours of exposure to a given activity is:

\[
m_a = m_0 \exp k_m a_v
\]  

(5)
where \( m_0 \) is the intercept value of the first order regression line with the activity (\( a_v \)) of 0.0 and \( k_m \) is the rate constant of mass change. Combining equation 5 with equation 2 gives the following statement:

\[
m_0 + \Delta w_{24} = m_0 \exp k_m a_v
\]  

(6)
The value of $m_0$ according to a first order was also calculated. The mass of water in the mite at time $t$ is (Wharton and Devine, 1960):

$$m_t = m_0 \exp(k_m t)$$

This equation can be solved for the rate constant, $k_m$, at of 30 hours. The value of $k_m$ would be the same for at the activity of 0.0, so the two equations can be set e other. Since $m_{30}$ is equal to $m$, these equal expressions:

$$1 \ln \left( \frac{m}{m_0} \right) = 30 \text{ hrs} \ln \left( \frac{m}{m_0} \right)$$

or the following:

$$\ln \left( \frac{m}{m_0} \right) = \ln \left( \frac{m}{m_0} \right)$$

The value of squares to the total su squares was calculated. A proportional test was then run on the activities. The mean observed values of $\Delta w_{24}$ were compared with the calculated zero order and first order $\Delta w_{24}$ values at each of the six test activities by chi-square tests with the null hypotheses that the observed $\Delta w_{24}$ did not fit either model.

The mean CEA can be determined for a zero order and a first order model of water mass with change in activity by solving equations 3 and 6 for $m$ when $\Delta w_{24}$ is zero.
The value of $m_6$ according to a first order model of mass change was also calculated. The mass of water in the mites at a given activity at time $t$ is (Wharton and Devine, 1960):

$$m_t = m_0 (\exp) k_m t$$  \hspace{1cm} (7)

This equation can be solved for the rate constant, $k_m$, at a $t$ of six and a $t$ of 30 hours. The value of $k_m$ would be the same for both expressions at the activity of 0.0, so the two equations can be set equal to each other. Since $m_{30}$ is equal to $m_f$, these equal expressions become:

$$6 \text{ hrs} \cdot \ln \left( \frac{m_6}{m_0} \right) = 30 \text{ hrs} \cdot \ln \left( \frac{m_f}{m_0} \right)$$  \hspace{1cm} (8)

or the following:

$$5 \ln \left( \frac{m_6}{m_0} \right) = \ln \left( \frac{m_f}{m_0} \right)$$  \hspace{1cm} (9)

The value of $m_6$ was arrived at by choosing values of $m_6$ and $m_f$ for equation 9 such that both sides were equal.

The ratio of the regression sum of squares to the total sum of squares was calculated for both regression lines. A proportionality test was then run on these ratios. The mean observed values of $\Delta w_{24}$ were compared with the calculated zero order and first order $\Delta w_{24}$ values at each of the six test activities by chi-square tests with the null hypotheses that the observed $\Delta w_{24}$ did not fit either model.

The mean CEA can be determined for a zero order and a first order model of water mass with change in activity by solving equations 3 and 6 for $a_v$ when $\Delta w_{24}$ is zero.
RESULTS

The response of *Dermatophagoides farinae*, with food present, to various activities gave a clear indication of the range of activities of interest in determining the CEA. At an activity of 0.55 and higher 50 percent or more of the mites survived for 15 days and a differential survival of the various instars was not noted. However, no eggs were laid at activities below 0.60.

The results of the studies of individually caged, fasting, standardized adult female *D. farinae* were equally clear. The values of $\Delta w_{24}$ varied as a function of the activity. The t-test of the homogeneity of the regression coefficients for the glycerol and potassium hydroxide data gave no reason to reject the null hypothesis that there was no difference between the data for the two solutions, so the data for the two solutions were pooled (Table 2).

The mean weight and standard deviation of 30 adult female *D. farinae* in equilibrium with the activity of 0.75 was 16.12 ± 1.9 µg. An average of 10.21 ± 2.1 µg or 63.3 percent of this weight was lost when 28 females were dehydrated to dry weight which would be 5.91 µg. The mites were apparently completely dry because the weights of the mites did not change when reweighed after 24 hours of further dehydration over redried silica gel.
Table 2. - The mean and standard deviation of $\Delta w_{24}$ in µg for the pooled data for each of the six test activities.

<table>
<thead>
<tr>
<th>$a_v$</th>
<th>number of mites</th>
<th>pooled data</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>10</td>
<td>$-4.19 \pm 1.21$</td>
</tr>
<tr>
<td>0.55</td>
<td>10</td>
<td>$-3.55 \pm 1.71$</td>
</tr>
<tr>
<td>0.60</td>
<td>20</td>
<td>$-2.37 \pm 1.59$</td>
</tr>
<tr>
<td>0.65</td>
<td>30</td>
<td>$-0.40 \pm 1.35$</td>
</tr>
<tr>
<td>0.70</td>
<td>30</td>
<td>$0.15 \pm 1.35$</td>
</tr>
<tr>
<td>0.75</td>
<td>30</td>
<td>$0.91 \pm 1.05$</td>
</tr>
</tbody>
</table>

According to a zero order model of mass change, equation 4 became:

$$m_t = t \left( -0.619 \ \mu g/\text{hr} \right) + 10.21 \ \mu g$$  \hspace{1cm} (10)

and at six hours gives a $m_6$ of 6.50 µg. This value of $m_6$ was added to the values of $\Delta w_{24}$, and the zero order regression equation calculated to be:

$$6.50 \ \mu g + \Delta w_{24} = a_v \ 21.93 - 8.71 \ \mu g$$  \hspace{1cm} (11)

which is graphed in figure 1.

The calculated value for $m_6$ according to a first order model of mass change was 7.28 µg. Adding this value of $m_6$ to the values of $\Delta w_{24}$ and calculating the first order equation for the data gave the following equation:

$$7.28 \ \mu g + \Delta w_{24} = 0.34 \ \mu g (\text{exp}) \ 4.36 \ a_v$$  \hspace{1cm} (12)

which is graphed in figure 2.
Figure 1. - A zero order least squares regression plot of mass, \( m_0 + \Delta m_{24} \), of mites exposed to six activities for 24 hours versus activity of the water vapor of the air to which they are exposed.
Figure 2. - A first order least squares regression plot of mass, \( m_0 + \Delta m_{24} \), of mites exposed to six activities for 24 hours versus activity of the water vapor of the air to which they are exposed.
\[(m_6 + \Delta v_{24}) \left[ a_v = 0.0 \right] = 0.3\]
The ratio of the regression sum of squares to the total sum of squares for the zero order regression line was 0.55, and the ratio for the first order line was 0.50. These values were not significantly different according to a binomial proportionality test, so the fit of the regression lines with the $m_6 + \Delta w_{24}$ data from the six test activities does not indicate whether a zero order or a first order model best describes the relationship between change in activity and water mass revealed in this study.

The mean values of $\Delta w_{24}$ determined by the zero order and first order regression lines, which are the differences at the test activities between the water mass in the mites predicted by the two models and the appropriate value of $m_6$, are given in table 3 along with the observed mean values of $\Delta w_{24}$. A chi-square test of the $\Delta w_{24}$ values for the zero order and observed values of $\Delta w_{24}$ gave a chi-square value of 33.9, and the comparison of the first order and observed values of $\Delta w_{24}$ gave a chi-square value of 42.3. With an n of 6 both of these chi-square values are significant at the 0.005 level, so the null hypotheses are rejected indicating that over the range of the test activities it can not be determined which model best describes the observed values of $\Delta w_{24}$.

The mean CEA for the zero order model of mass with change in activity was 0.69, and the mean CEA for the first order model was 0.70. However, there is no significant difference between these two mean values of the CEA. At the activity of 0.65 eight of the 30 mites tested gained weight, at the activity of 0.60 one of the 20 mites tested gained weight, and at the activity of 0.75 three of the 20 mites tested lost weight.
Table 3. - The mean values of Δω_24 determined by the regression lines and the observed mean values of Δω_24 for the six test activities.

<table>
<thead>
<tr>
<th>a_v</th>
<th>Zero Order</th>
<th>First Order</th>
<th>Observed</th>
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<td>1.24</td>
<td>1.76</td>
<td>0.91</td>
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<td>0.14</td>
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<td>-2.73</td>
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DISCUSSION

The aqueous solutions

Besides the characteristic water vapor pressure associated with each of the various concentrations of the glycerol and potassium hydroxide solutions, there is also a characteristic glycerol or potassium hydroxide vapor pressure. However, at 25°C these vapor pressures are very small for the vapor pressure of pure glycerol is only 1 mm at 125.5°C and drops to 0.0025 mm at 50°C (Newman, 1968), and the vapor pressure of potassium hydroxide is only 1 mm at 719°C (Jackson and Morgan, 1921). The difference in temperature at which the vapor pressures of glycerol and potassium hydroxide are 1 mm also suggests that at 25°C the vapor pressure of glycerol will be larger than the vapor pressure of potassium hydroxide.

With the very small vapor pressures involved at 25°C the only feasible influence the glycerol and/or potassium hydroxide molecules in the air could have on water balance would be to interact in someway with the pump involved in moving water across the integument. The fact that no significant differences between the values of $\Delta w_{24}$ from the two solutions were detected indicates one of two things was occurring. Either the solute vapors had no influence or so small an influence on water movement that it could not be detected with the test conditions used, or both affected water movement just to the extent that the
resulting values of $\Delta w_{24}^{24}$ for both solutions were not significantly different. For the latter to be true the vapor molecules of glycerol and potassium hydroxide would have to have equal influences on the water pump at each of the activities tested even though the concentrations of the two vapors would be different. The probability of this being the case seems more remote than if it is assumed that glycerol and potassium hydroxide vapors do not affect the net water movement observed.

**Net change in weight**

Fasting mites were used in this study in order that the changes in weight observed would reflect only water movement through the integument rather than also include water movement from the alimentary tract. Besides the fact that the mites were caged apart from food for 30 hours before weight changes were recorded, the reddish-brown color of dog food readily visible in the gut of mites that had recently fed was not seen for any of the test females prior to being caged. For these reasons it was assumed that the mites were fasting when tested.

Of course the fasting animals were benefiting from water derived from the oxidation of food reserves, but Kanungo (1965) and Edney (1966) found that this was only a very small fraction of the net water gain for organisms they studied. For example, if the oxygen consumption of *L. echidnina* per mite per hour (Kanungo, 1965) is used and if only fat were oxidized, there could be a gain in weight in 24 hours of 0.34 ug. If only carbohydrates were oxidized, there would be a net loss in weight in 24 hours of 0.50 ug. If the oxygen consumption of *D. farinae*
decreases by a factor of ten as does the weight difference between L. echidnina and D. farinae, the maximum weight gain in 24 hours from the oxidation of only fats for D. farinae would be 0.03 ug. Even if fasting adult female D. farinae did oxidize only fat which seems unlikely, the possible weight gain in 24 hours is too small to significantly affect the weight changes recorded.

Excretion and reproduction did not enter into the net movement of water that was recorded. In the cages of mites held 48 hours without dehydration one to three eggs were usually found along with numerous droplets of excretion. In the cages of mites which were tested, eggs and/or evidence of excretion were found in about ten percent of the cages, and the data from these individuals were not included in the results.

Movement of the mites during testing was minimal. Movement of the mites ceased shortly after being caged, and invariably the mites stopped in a fold of the foil of the cage near the screen where both the venter and the dorsum touched the foil. At the end of a test where 20 cages were taken apart on which the initial resting position of the mites was marked, all of the mites were in the same position. Therefore, it was assumed for this study that the rates of water movement were not influenced by the movement of the mites.

Because Dermatophagoides lack a tracheal system and because water was not lost in reproduction, egestion or excretion, water loss from the adult female D. farinae could have occurred only via cuticular transpiration. Since no food or free water was available to the caged mites and
water gain from the oxidation of reserve food is so small, the gain in weight can only be accounted for by sorption of water vapor from the air through the cuticle.

Critical equilibrium activity

A CEA of 0.70, which represents the lowest mean activity at which sorption will equal transpiration for fasting, resting adult female _D. farinae_, is essentially the same CEA observed for the grain mite, _Acarus siro_, which also lacks a tracheal system. However, the tick larvae that Knülle (1967) tested which likewise lack a tracheal system, have a CEA considerably higher than 0.70, so the lack of a tracheal system in mites does not necessarily correlate with a low CEA.

If the fasting of the mites were to be continued, the CEA sooner or later would rise as occurs in _Ixodes ricinus_ (Lees, 1964), or the mites would begin to lose water as occurs in _Acarus siro_ (Knülle, 1965). With food present, however, the preliminary experiment of this study indicates that females can survive 15 days at activities at least ten points below the CEA measured. Dog food in equilibrium with an activity of 0.75 contains 15 percent water by weight (unpublished data), so enough water could have been present in the food to account for the mites maintaining water balance even at activities below 0.70.

The ability of _D. farinae_ to exploit a mattress and stuffed furniture habitat (Larson et al., in press) is undoubtedly enhanced by the capability of at least the females to maintain a water balance at an activity as low as 0.70. In fact _D. farinae_ females may well survive
at activities below 0.70 for they should be just as capable of surviving in a daily dehydration-rehydration cycle as was *L. echidnina* (Knülle, 1967a). As long as the activity rises above 0.70 long enough during 24 hours for the animals to gain back the water lost at activities below the CEA, water balance could be maintained. In house dust this would most likely occur when the inhabitants of the house used the mattress or stuffed furniture, and the moisture from the person's body raised the activity in the house dust above the CEA.

**Water exchange kinetics**

Zero and first order models of water mass left in the mites with change in activity were proposed to describe the $m + \Delta m_{24}$ data, and the amount of water left in the mites at the activity of 0.50 according to the two models suggested that a first order model was the more probable. The zero order regression line when extrapolated to the activity of 0.0 predicts that a mite exposed for 24 hours at that activity could lose 15.21 μg of water or 8.71 μg more water than the mite had available to lose. On the other hand the first order regression line when extrapolated to the activity of 0.0 predicts that at the end of 24 hours there would still be 0.345 μg of water left in the mites. Since the zero order model predicts more water would be lost than the mites had to lose, it is concluded that a first order model is a better description of the water mass left in the mites with change in activity.

While the values predicted by the extrapolation of the regression lines were used as the basis to make the above conclusion, the
extrapolated values do not accurately describe the water movement that would occur in 24 hours at most of these untested activities. For example, at some activity between 0.50 and 0.0 mites are going to die before the 24 hours of dehydration at the particular activity are over, and the death of the mites will result in an increase in the rate of water loss until static equilibrium with the activity is reached which will be reflected by a change in the slope of the regression line for those activities at which death occurs before 24 hours are past. However, like the extrapolation of temperature to absolute zero which can only be done ideally, the zero and first order extrapolations may be considered ideally where the water loss at the end of 24 hours at the activity of 0.0 is thought of as having been lost from a mite that is still alive. Like the value of absolute zero this establishes a benchmark that permits a meaningful conclusion to be reached about the models behind the extrapolations.

Similarly, at activities above the CEA the extrapolated values for \( m_6 + \Delta w_{24} \) are not necessarily accurate descriptions of water movement that would occur in 24 hours. This is true because there is a characteristic equilibrium weight for each activity above the CEA which probably is reached at activities higher than 0.75 before the 24 hours are over, and once the equilibrium weight is reached net mass change is zero which means sorption and transpiration are equal. If this were not the case and sorption was always greater than transpiration there would continue to be a net gain in water above the CEA until the organism burst due to the internal water pressure. However, an accurate
description of water movement for those activities at which death occurs or equilibrium is reached before 24 hours of exposure to the test activities would be over can be made if mass change is measured on an hourly basis.

At least two points can be determined for each of the rate constants, \( k_m \), \( k_S \) and \( k_T^* \), from the information that is available provided certain assumptions are made. By definition \( k_m \) is zero at the CEA as is \( k_T \) at the water vapor activity of 0.0. Likewise, at the activity of 0.0 \( k_m \) is equal to \(-k_T^*\), and \( k_m \) was calculated in determining the first order \( m_0 \) to be \(-0.0564\) per hour. Given a surface limited organism at isothermal and isobaric conditions, the simplest model for the transpiration rate constant would be for it to be a constant value at all activities; and if this is assumed to be the case, the value for \( k_T^* \) at all activities is \(0.0564\) per hour. This would also be the value of \( k_S \) at the CEA which establishes two points for \( k_S \). Since a first order model of mass change with change in activity means that the rate constants would change by an exponential factor with change in activity, the constants were graphed on semi-logarithmic paper using 0.02 plus the values estimated as indicated above. Such a graph provides an approximate visualization of the relationships among the constants (Figure 3). At the CEA sorption will equal transpiration which means this is the first point at which an equilibrium weight can be established, and these relationships are indicated in Figure 3 by dashed lines.
Figure 3. - The rate constants, $k_m$, $k_S$, and $k_*$, based on two points established for each constant versus activity of the water vapor of the air to which they are exposed.
CONCLUSIONS

1. The mean critical equilibrium activity for the fasting, resting adult females of *Dermatophagoides farinae* is 0.70. However, weight was gained by an individual mite at an activity as low as 0.60, and weight was lost by individual mites at the activity of 0.75.

2. The glycerol and potassium hydroxide vapor in the air of the test activities at 25°C did not influence the water mass changes observed.

3. A first order model is a better description of the water mass in the mites with change in activity than is a zero order model when extreme conditions are taken into account, but neither model can be considered as more than an approximate description of the relationships between water exchange of *D. farinae* females and ambient water vapor activity.
LITERATURE CITED


