Evaluating the Lethality of Heat Processes
Using a Method Employing Hicks' Table

I. J. Pfug
Department of Food Science, Michigan State University, East Lansing, Michigan

SUMMARY
A method of calculating the lethality of heat processes is described and illustrated. This method can be used for z-values from 10 to 80°F; it allows the technologist to calculate directly the lethality of the heating and the cooling portion of the process.

METHOD
Hicks (1958) prepared a set of tables, where the term that we shall call \( H \), which is a function of \( g \) and \( z \), is tabulated; the term \( H \) in these tables is related to \( f_s \), \( U_s \), \( c \), \( f_s \), and \( U_s \), in the equation:

\[
H = \frac{100 U_s}{c} \times \frac{100 U_s}{f_s}
\]

The function \( H \) is quite similar to the function \( f_s/U \) of Ball (1928). (We shall use the symbol \( B \) for Ball's function, \( B = f_s/U \)). The significant difference between the function \( B \) and the function \( H \) is that \( B \) relates \( U \), the lethal effect of both the heating and cooling portions of the thermal process, with \( f_s \), whereas \( H \) relates \( U_s \), the lethal effect of the heating portion of the curve, with \( f_s \), and through the use of \( c \) relates \( U_s \), the lethal effect of the cool, with \( f_s \) (\( c = U_s/U_s \)). The potential use of Hicks table was recognized soon after it appeared in 1958; however, to bring the Hicks table (Table 1) into practical use it was necessary to develop the tables of \( c \) (Tables 2 and 3). The \( c \) tables were developed using the data in the cooling tables of the new calculation method in Ball et al. (1957). The variable \( c \), in its most usable form, relates \( H \), \( f_s \), and \( U_s \), in the equation:

\[
U_s = \frac{cHf_s}{100}
\]

This method of process evaluation, which is applicable for z values of 10 through 80 and for simple through very complex heating and cooling curves, is, in reality, a simplification of the new formula method of Ball et al. (1957). The method described here, using Hicks tables, was designed to solve less complicated problems than the new formula method of Ball et al. (1957).

In using the Hicks-tables method, the heating and cooling portions of the process are treated separately; in the case of the simple heating curve, the value of Hicks function is obtained directly from Table 1. When \( g \) is less...
EVALUATING HEAT PROCESSES WITH HICKS TABLE

Table 1. Table of values of Hicks (1958) function "H" where \( H = \frac{100U_t}{t_e} \). (From Food Research 23, pages 396-400, 1958.)

<table>
<thead>
<tr>
<th>( t_e )</th>
<th>( t_e )</th>
<th>( t_e )</th>
<th>( t_e )</th>
<th>( t_e )</th>
<th>( t_e )</th>
<th>( t_e )</th>
<th>( t_e )</th>
<th>( t_e )</th>
<th>( t_e )</th>
<th>( t_e )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>0.20</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<td>1.00</td>
</tr>
<tr>
<td>0.25</td>
<td>1.00</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>0.30</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>0.40</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 2. Table of values of c (\( c = \frac{U_t}{H} \)).

<table>
<thead>
<tr>
<th>( (T_e - T_0) = 125°F )</th>
<th>( e )</th>
<th>( 15 )</th>
<th>( 20 )</th>
<th>( 25 )</th>
<th>( 30 )</th>
<th>( 40 )</th>
<th>( 60 )</th>
<th>( 80 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>0.5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<td>0.00</td>
</tr>
<tr>
<td>1.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

than 0.1°F (\( g \) is less than -1.0) the value of \( H \) for \( g = 0.1°F \) is used but must be increased by a factor \( H_e \) obtained from Fig. 1 (\( H = H_{e,1} + H_e \)).

The lethal effect of the cool \( U_t = eH_t \); values of \( e \) are tabulated in Table 2. When \( g > 0.1°F \) the cooling lethality is found by determining \( H \) as a function of \( g \) and \( z \), \( e \) as a function of \( g \), \( (T_e - T_0) \) and \( z \) after which the value \( U_t \) can be found using the equation

\[
U_t = \frac{eH_t}{100}
\]

The lethality of heating plus cooling is found using the equation

\[
U = U_t + U_e = \frac{H_{e,1} + H_e}{100} + \frac{eH_t}{100}
\]

It is assumed that there is no difference in the lethal effect of the cool when \( g = 0.1°F \) and when \( g = 0°F \); therefore, for all values of \( g \) equal to or less than 0.1°F, the value of the function \( eH/100 \) for \( g = 0.1°F \) the
Evaluating heat processes with Hicks table continued

Table 3. Values of \( \frac{cH}{100} \) for \( g = 0.1^\circ F \) for use in calculating the cooling curve lethality.

<table>
<thead>
<tr>
<th>( g, ^\circ F )</th>
<th>( \frac{(T_2-T_0)}{100} )</th>
<th>( \frac{(T_1-T_2)}{100} )</th>
<th>( \frac{(T_0-T_2)}{100} )</th>
<th>( \frac{(T_1-T_0)}{100} )</th>
<th>( H )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.124</td>
<td>0.115</td>
<td>0.107</td>
<td>0.109</td>
<td>1.08</td>
</tr>
<tr>
<td>15</td>
<td>0.139</td>
<td>0.125</td>
<td>0.111</td>
<td>0.113</td>
<td>1.08</td>
</tr>
<tr>
<td>20</td>
<td>0.150</td>
<td>0.127</td>
<td>0.110</td>
<td>0.112</td>
<td>1.08</td>
</tr>
<tr>
<td>30</td>
<td>0.171</td>
<td>0.128</td>
<td>0.110</td>
<td>0.107</td>
<td>1.05</td>
</tr>
<tr>
<td>40</td>
<td>0.191</td>
<td>0.128</td>
<td>0.110</td>
<td>0.105</td>
<td>1.04</td>
</tr>
<tr>
<td>60</td>
<td>0.528</td>
<td>0.188</td>
<td>0.154</td>
<td>0.129</td>
<td>1.00</td>
</tr>
<tr>
<td>80</td>
<td>0.527</td>
<td>0.229</td>
<td>0.202</td>
<td>0.158</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Values of \( cH/100 \) for \( g = 0.1^\circ F \) is less than \( 0.1^\circ F \) as a function of \( z \) and \( (T_1 - T_0) \) are tabulated in Table 3.

In general, heat processing conditions may be thought of as either having simple heating curves with \( f_z = f_z \), simple heating curves with \( f_z \neq f_z \), or complex heating curves consisting of \( f_z, f_z \), and \( f_z \). The procedure using Hicks tables may be used equally well to analyze data from all three process situations. Symbols for use with a simple heating curve are diagrammed in Fig. 2A and for a complex heating curve in Fig. 2B.

The Hicks-table method of analysis of heat processes where the heating curve is complex is carried out by dividing the process into sections analyzing each section separately and summing up the parts to complete the solution. The process is divided at the time point when the semi-logarithmic heating curve changes slope. The subscripts used in the equations below correspond to those used in Fig. 2. The significance of the subscripts is to relate the value of \( g \) used in arriving at \( H \) and the value of \( f_z \) used with \( H \) to arrive at the \( U_z \). In general, when the term \( U \) is used, without subscript, it implies that it is the total lethal effect of both heating and cooling for the entire process. The subscripts refer to the sections of the process and may be either heating or cooling according to the respective subscripts as shown below:

\[
U = U_z + U_{z1} - U_{z,t} \quad \text{for} \quad (T_1 - T_0, f_z, j, t_z) \quad \text{(or} \quad t_{z1}) \quad \text{if} \quad f_z \quad \text{is not given we will assume that} \quad f_z = f_z; \quad j \quad \text{must be known or assumed to be} \quad 1.41.
\]

2. Calculate \( \log g \) using the equation

\[
\log g = -t_z/f_z + \log j (T_1 - T_0)
\]

3. Using the data in Table 1 determine \( H \) for the particular value of \( \log g \) and \( z \).

4. Using Table 2 determine the value \( c \) as a function of \( \log g \), \( z \), and \( (T_1 - T_0) \).

5. Calculate \( U \) using the equation

\[
U = \frac{Hf_z}{100} + \frac{chf_z}{100}
\]

Example: Simple heating, \( g \) is greater than \( 0.1^\circ F \) \( (\log g > 1.0) \).

1. Data:

\[
\begin{align*}
T_1 &= 245^\circ F \\
T_0 &= 160^\circ F \\
T_2 &= 65^\circ F \\
t_z &= 80.0 \text{ min} \\
f_z &= 48.0 \text{ min} \\
\log g &= -t_z/f_z + \log j (T_1 - T_0) \\
&= -80/48 + \log 1.5 \\
&= 0.441.
\end{align*}
\]

2. From Table 1, \( H = 35 \).

3. From Table 2, \( c = 0.27 \).

5. Calculate \( F_{cw} \) using the equation

\[
F_{cw} = U \text{ min} = 21.3 \text{ sec}
\]

Example: Simple heating, \( g \) is less than \( 0.1^\circ F \) \( (\log g < 1.0) \).

1. Data:

\[
\begin{align*}
T_1 &= 250^\circ F \\
T_0 &= 140^\circ F \\
T_2 &= 75^\circ F \\
(T_1 - T_0) &= 175^\circ F \\
t_z &= 35 \text{ min} \\
f_z &= 8 \text{ min} \\
\log g &= -t_z/f_z + \log j (T_1 - T_0) \\
&= -35/8 + \log 1.5 \\
&= 0.27 \times 35 \times 48 = 21.3.
\end{align*}
\]

6. \( F_{cw} = (U \times \text{lethality ratio}) \)

245\(^\circ\)F, \( z = 18 \) = 21.3 \( \times 0.527 \)

\[= 11.2 \text{ min} \]

Example: Simple heating, \( g \) is greater than \( 0.1^\circ F \) \( (\log g > 1.0) \).

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245\(^\circ\)F, \( z = 18 \) = 21.3 \( \times 0.527 \)

\[= 11.2 \text{ min} \]
EVALUATING HEAT PROCESSES WITH HICKS TABLE concluded

2. log g = -t/t, + log j (T, - T,) log g = -35/3 + log 12.1 (110) = -4.375 + 2.121 = -2.254 g = 0.0055°F

3. g is less than 0.1°F therefore
H = H + H from Table 1, H = 193.4
from Fig. 1, H = 125
H = 193.4 + 125 = 318.4

4. From Table 3 cH /100 = 0.158.
5. F = U = H, + cH, = H, 318.4 × 8 + 0.158 × 100
100 12 = 27.4 min

Example: Complex heating curve (two-slope type)

1. Data:
T, = 245°F
T, = 140°F
T, = 65°F
z = 18°F
j = 1.73
f, = 12.1 min
f, = 20.1 min
f, = 40 min
f, = 23.7 min
assumed j is 1.41

2. Calculation of g, and g, log g, = -t, /T, + log j (T, - T,)
log g, = -1.661 + 2.259 = 0.598
-(T, - T,)

3. Determine H from Table 1
H, = 24.1
H, = 55.0

4. From Table 2, e = 0.196.
5. Calculate U where U = U, + U, U, = 24.1 × 12.1 2.92 min.
100
U, = (55.0 - 24.1) 46.4 14.34 min.
100

6. F = U, = 0.196 × 55.0 × 23.7 2.55 min.
100

U, = 2.92 + 14.34 + 2.55 = 19.81 min.

ADVANTAGES OF THE METHOD
1. This method makes it possible for the food technologist or microbiologist to calculate the lethality of heating processes for z-values from 10 to 80°F.
2. It makes possible the use of the data in the tables of Ball et al. (1937) with their improved accuracy for solving both simple and complex heat processing problems.
3. It allows the technologist to directly calculate the lethality of the heating and cooling portion of the process.

NOMENCLATURE
B, symbol for Ball (1932) function, f
r, ratio of heating lethality to cooling lethality, e = U, / U,
F, the equivalent time of a heat process at temperature T for a temperature coefficient value z
f, the temperature response parameter, the time for the straight line asymptote of the semilogarithmic heating or cooling curve to traverse one log cycle, f, for heating, f, for cooling, f, f, f, ... respective temperature response parameters for complex heating curves.
z, degrees F below medium temperature = (T, - T)
H, symbol for Hicks (1958) function = 100 U, / 100 U,
T, symbol for Hicks (1958) function = 100 F/min at T = 250

REFERENCES
Hicks, E. W. 1958. A revised table of the F, function of Ball and Olson. Food Research 23, 396.
Ms. accepted 3/27/58.

The author is appreciative of the assistance in developing this method: I. J. Kopelman calculated the table of values of e; students in several classes of MSU FSC-830 made recommendations for improving the method.