We are embarking on a trip to Osaka, Japan in May. The temperature of Osaka at night is predicted to be around 15°C. Therefore we will need to wear slightly thicker clothing there. Despite the thick clothing, our body will continuously lose heat when we are outdoors. Hence, the objective of this mini project is to find out how long we can stay outdoors at night in Osaka before we start to experience mild hypothermia, which occurs at approximately 35°C.

This models an **UNSTEADY STATE 2-Dimensional heat transfer** problem.

- We have fixed the geometry of the human body to be a cylinder of 1.70m height and 0.22064 m in diameter
- Prior to leaving for outdoors, we assume that initially, the human body has uniform distribution of heat throughout its core and extremities. Hence, \( T_{A,0} = T_{B,0} = 37^\circ\text{C} \).
- Additionally, since the layer of clothing is very thin, we further establish that the temperature gradient across the clothing is negligible such that \( T_{S,0} = 37^\circ\text{C} \).
- In order to determine the lower threshold time taken for the onset of mild hypothermia, we have to assume body heat generation to be zero since body heat generation only sets to prolong the onset time.

Hence \( q_{\text{generation}} = 0 \), to find this limiting case.

Due to varying surface temperatures, we first approximate our film temperature, \( T \) using initial conditions.

\[
T_{f,0} = \frac{37 + 15}{2} = 26\,^\circ\text{C} = 299.15\,K
\]

Properties of air at 299.15 K to be given as the following,

<table>
<thead>
<tr>
<th>( k_{\text{air}} ) (W m(^{-1})K(^{-1}))</th>
<th>( Pr )</th>
<th>( \frac{g \beta \rho^2}{\mu^2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.61733175 \times 10^{-2}</td>
<td>0.7082125</td>
<td>1.34774 \times 10^{8}</td>
</tr>
</tbody>
</table>

\[
Gr_L = \frac{g \beta \rho^2}{\mu^2} L^3 \Delta T = (1.34774 \times 10^8)(1.71^3)(37 - 15) = 1.48258 \times 10^{10}
\]

\[
\frac{D}{L} = \frac{0.23064}{1.71} = 0.13488 \quad \frac{35}{Gr_{0.25}} = 0.1003029628
\]

Since \( \frac{D}{L} > \frac{35}{Gr_{0.25}} \), a vertical cylinder can be evaluated using correlations for vertical plane walls

\[
Ra_L = Gr_L Pr = 1.0500 \times 10^{10}
\]

**For vertical plane walls,**

\[
Nu_L = \left( 0.825 + \frac{0.387}{1 \left( 1 + (0.492/Pr)^{16} \right)^{1/8}} \right)^2 = 256.10679
\]

\[
h_L = \frac{Nu_L k}{L} = \frac{256.10679 \times 2.61733 \times 10^{-2}}{1.71} = 3.9200 \, W \, m^{-2} \, K^{-1}
\]
For horizontal plates.

Wetted parameter, \( L = \frac{A}{\rho} = \frac{nD^2}{\pi D} = \frac{D}{4} = 0.05766m \)

\[ \text{Gr}_{\text{top}} = \text{Gr}_{\text{bottom}} = \frac{g \beta \rho^2}{\mu^2} L^3 \Delta T = (1.34774 \times 10^8)(0.05766^3)(37 - 15) = 568398.2251 \]

\[ \text{Ra}_{\text{top}} = \text{Ra}_{\text{bottom}} = \text{Gr}_{\text{top}} \Pr = 568398.2251 \times 0.7082125 = 402546.728 \]

Since \( 10^5 < \text{Ra}_{\text{top}} < 2 \times 10^7 \), \( \text{Nu}_{\text{top}} = 0.54 \text{Ra}_{\text{top}}^{1/4} = 13.601845 \)

\[ h_{\text{top}} = \frac{13.601845 \times 2.61733 \times 10^{-2}}{0.23064} = 1.54355 \text{ W m}^{-2} \text{ K}^{-1} \]

Since \( 3 \times 10^5 < \text{Ra}_{\text{bottom}} < 10^{10} \), \( \text{Nu}_{\text{bottom}} = 0.27 \text{Ra}_{\text{bottom}}^{1/4} = 6.8009 \)

\[ h_{\text{bottom}} = \frac{6.8009 \times 2.61733 \times 10^{-2}}{0.23064} = 0.77177 \text{ W m}^{-2} \text{ K}^{-1} \]

Taking the weighted area average,

\[ h_{\text{ave}} = \frac{A_{\text{top}}}{A_{\text{total}}} h_{\text{top}} + \frac{A_{\text{bottom}}}{A_{\text{total}}} h_{\text{bottom}} + \frac{A_{\text{side}}}{A_{\text{total}}} h_L = 3.745475 \text{ W m}^{-2} \text{ K}^{-1} \]

We further assume the human body to have the properties of water since water constitutes 70% of the human body. At 310K, properties of water: \( k = 0.6276 \), \( \alpha = 0.1515 \times 10^{-6} \text{ m}^2/\text{s} \)

\[ \text{Bi} = \frac{hV}{k_{\text{human}}A} = \frac{h \times \pi D^2}{4 \left( \pi D + \frac{\pi D^3}{2} \right)} = \frac{3.745475 \times \frac{\pi 0.23064^2 \times 1.71}{4}}{0.6276 \left( \pi 0.23064 \times 1.71 + \frac{\pi (0.23064)^2}{2} \right)} = 0.32237 \]

Since \( 0.1 < \text{Bi} < 100 \), the Heislei charts are used (WWWR textbook Appendix F, Figure 7 & 8).

\[ Y = \frac{T_{a} - T}{T_{a} - T_{o}} = \frac{15 - 35}{15 - 37} = 0.91 = Y_a Y_{CL} \]

\[ n_{CL} = \frac{x}{x_1} = 0.9566424, \quad m_{CL} = \frac{k}{h x_1} = 1.4530, \quad x_{CL} = \frac{\alpha_{\text{human}} t}{x_1^2} = 1.1392 \times 10^{-5} t \]

\[ n_a = \frac{x}{x_1} = 0.99415 \approx 1, \quad m_a = \frac{k}{h x_1} = 0.1960, \quad x_a = \frac{\alpha_{\text{human}} t}{x_1^2} = 2.0724 \times 10^{-7} t \]

<table>
<thead>
<tr>
<th>( t/s )</th>
<th>( X_{CL} )</th>
<th>( m_{CL} )</th>
<th>( n_{CL} )</th>
<th>( Y_{CL} )</th>
<th>( X_a )</th>
<th>( m_a )</th>
<th>( n_a )</th>
<th>( Y_a )</th>
<th>( Y = Y_a Y_{CL} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000</td>
<td>0.11392</td>
<td>1.4530</td>
<td>0.9566424</td>
<td>0.78</td>
<td>2.072E-3</td>
<td>0.1960</td>
<td>1</td>
<td>1</td>
<td>0.78</td>
</tr>
<tr>
<td>5000</td>
<td>0.05696</td>
<td>1.4530</td>
<td>0.9566424</td>
<td>0.84</td>
<td>1.036E-3</td>
<td>0.1960</td>
<td>1</td>
<td>1</td>
<td>0.84</td>
</tr>
<tr>
<td>2400</td>
<td>0.02734</td>
<td>1.4530</td>
<td>0.9566424</td>
<td>0.91</td>
<td>4.974E-4</td>
<td>0.1960</td>
<td>1</td>
<td>1</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Therefore, the lower threshold time taken for the onset of mild hypothermia is approximately 2400s (40 minutes).
Introduction
In this project, we will find out if the 3 minutes cooking time as suggested by the instant noodle manufacturer is valid.

Typical net weight of noodles in 1 packet of instant noodles = 85g (information obtained from packaging of instant noodles)
Diameter of noodles ≈ 1mm
Initial temperature of uncooked noodles = 25°C

Calculating the convective heat transfer coefficient of water at 100°C:
Assumptions:
(i) Temperature of boiling water is constant at 100°C
(ii) The composition of water remains unchanged, and hence the properties of water remain unchanged
(iii) Assume the 15cm by 15cm square base of the cooking pot is large such that it mimics natural convection on a horizontal plate
(iv) Base of the cooking pot is maintained at a constant temperature of 150°C
(v) Assume heating of water only occurs from the base of the pot and none from the sides.

\[ T_f = \frac{T_s + T_{\infty}}{2} = \frac{150 + 100}{2} = 125 \]

At 125°C, properties of liquid water:
- \( \frac{g \beta \rho^2}{\mu^2} = 193.1175 \times 10^9 K^{-1} m^{-3} \)
- \( k = 0.67775 W/m \cdot K \)
- \( Pr = 1.525 \)

Values taken from Appendix I of WWWR textbook

\[ Gr = \frac{g \beta \rho^2}{\mu^2} (\Delta T)L^3 = (193.1175 \times 10^9)(150 - 100)(0.15)^3 = 3.2588 \times 10^{10} \]
\[ Ra = Gr \cdot Pr = (3.2588 \times 10^{10}) \times 1.525 = 4.96975 \times 10^{10} \]

For a hot surface facing up,
\[ Nu = 0.14 \cdot Ra^\frac{1}{3} = 0.14(4.96975 \times 10^{10})^{\frac{1}{3}} = 514.722 \]
\[ Nu = \frac{hL}{k} \Rightarrow h = \frac{Nu \cdot k}{L} = \frac{(514.722)(0.67775)}{0.15} = 2325.687 W/m^2 \cdot K \]

Calculating the time taken to cook instant noodles in boiling water:
Assumptions to simplify the calculation:
(vi) Properties of noodles = properties of water at 100°C since the water content in noodles is high during cooking.
(vii) Noodles are infinitely long cylinder
(viii) Heat transfer into noodles is only by conduction
(ix) Noodles do not expand during the course of cooking
(x) Temperature of boiling water is constant at 100°C
(xi) Noodles are cooked once the temperature in the core reaches 90°C (since it’s instant noodles)
At 100°C, 

\[
\begin{array}{|c|c|c|}
\hline
k & 0.682 W/m \cdot K & c_p = 4211 J/kg \cdot K & \rho = 958.4 kg/m^3 \\
\hline
\end{array}
\]

Values taken from Appendix I of WWWR textbook

\[
Bi = \frac{hY^k}{k} = \frac{2325.687(0.001)}{0.682} = 0.8525
\]

\[
\Rightarrow \text{The Temperature-Time Charts are used.}
\]

\[
a = \frac{k}{\rho c_p} = \frac{0.682}{(958.4)(4211)} = 1.689866 \times 10^{-7} m^2/s
\]

\[
Y = \frac{T_x - T}{T_x - T_0} = \frac{100 - 90}{100 - 25} = 0.1333
\]

\[
n = \frac{x}{x_1} = \frac{0}{0.5} = 0
\]

\[
m = \frac{k}{hx_1} = \frac{2325.687 \times 0.5}{1000} = 0.58649
\]

\[
\Rightarrow \text{from Fig.F5 of WWWR, } X = 1.0 = \frac{at}{x_1^2}
\]

\[
t = (1.0) \left( \frac{0.5}{100} \right)^2 + (1.689866 \times 10^{-7}) = 147.878s = 2.46 \text{ min}
\]

\[
\therefore \text{The time taken to cook 1 packet of instant noodles in boiling water is approximately 2.46 min, and this value corresponds to the recommended cooking time for instant noodles of 2 to 3 minutes as stated at on the packaging material.}
\]

Error Analysis and Evaluation

(i) The property of noodles was assumed to be equivalent to that of water, which is not a very accurate assumption at the initial stage of cooking.

(ii) The noodles actually expand and absorb water in the process, thus its property changes and is also different from the assumed property of noodles.

(iii) The proximity of the strands of noodles is close enough such that it affects the heat transfer to noodles. This was not considered in our calculations.

(iv) The boiling water means that there are bubbles that rise from the bottom of the pan to the water surface. This affects the assumption that heat transfer to the noodles is by conduction and convection from the liquid water.

(v) For horizontal plate, the recommended Ra range for the equation of Nu is $2 \times 10^{-7}$ to $3 \times 10^{-10}$. But in this case, the Ra is out of this range. Hence extrapolation was used

Conclusion

We found that the time needed to cook the noodle is 2.46 minutes. This value falls within the 3 minutes suggestion, however it should be noted that the assumptions we made will add uncertainty to our results. Hence our calculated value is only an estimation to verify if the recommended cooking time is valid. Ultimately, the best way to find out if the noodles is cooked to your preference (hard or soggy) or not is to try a noodle from the pot and decide if you want to turn off the fire or continue to let it boil. Afterall, the recommended cooking time is a range of 2 to 3 minutes, subjected to personal preference.

References:

Lollipop Size and Consumption Time

Introduction
Lollipop has been a very popular candy snack among kids and juveniles for decades. In this mini project, the relation between lollipop size and time for lollipop consumption is explored and suggested size of lollipop is given to with current product design size.

The mechanism for lollipop consumption is related to the diffusion of the components in saliva and continuous removal of it by swallowing motion. The pseudo steady state at the surface of the lollipop can be applied to calculate the disappearing rate of the candy sphere and Chilton-Colburn analogy is used to calculate the mass convection rate of components into saliva. Major ingredients of common lollipop are white sugar (sucrose), corn syrup (glucose) and other additives. Sucrose and glucose are used in our model.

Data

<table>
<thead>
<tr>
<th></th>
<th>Sucrose (C_{12}H_{22}O_{11})</th>
<th>Glucose (C_{6}H_{12}O_{6})</th>
<th>Saliva (H_{2}O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffusivity D_s</td>
<td>4.3×10^{-6} cm^2/s</td>
<td>6.7×10^{-6} cm^2/s</td>
<td></td>
</tr>
<tr>
<td>Diffusivity D_g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solubility(water)</td>
<td>200 g/100mL</td>
<td>91 g/100mL</td>
<td></td>
</tr>
<tr>
<td>Molar weight M_s</td>
<td>342.3 g/mol</td>
<td>180.16g/mol</td>
<td></td>
</tr>
<tr>
<td>Density of crystal ρ_s</td>
<td>1.588 g/cm^3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density of crystal ρ_g</td>
<td>1.380 g/cm^3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density of water ρ_w</td>
<td>1.000 g/cm^3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Possible volume ratio of sugar and corn syrup is 1:1/3 to 1:½.

Model calculation
Saliva flows through the surface of lollipop (spherical geometry) and the average flow cross-section area is calculated as

\[
\bar{S} = \frac{2}{2R} \int_0^R 2\pi R r \delta r = \frac{\pi R \delta}{2} \quad \text{--- (1), where } \delta \text{ is the thickness of the layer on the surface of lollipop. The concentration of components in the sugar film is assumed 100% of maximum solubility in the saliva (water).}
\]

Using Chilton-Colburn Analogy

\[
j_D = \frac{C_f}{2} = \frac{k_e}{\nu} \quad \text{--- (2)}
\]

\[
Re_D = \frac{\nu D}{\nu} = \frac{v \times 2R}{\nu} = \frac{2V}{\pi \delta \nu} \quad \text{--- (3)}
\]

\[
\nu = \frac{V}{\bar{S}} \quad \text{--- (4)}
\]

\[
k_{ei} = \frac{4 \nu}{R} \times \left( \frac{D_i}{\nu} \right)^2 \quad \text{--- (5)}
\]

where \( C_f = \frac{16}{Re_D} \) since the saliva flow rate is considered to be laminar.

Reynolds number where \( \nu \) is the flow velocity of saliva on the surface of lollipop.

Mass convection factor where \( i = s, g \).

It has no relation with saliva velocity or flow rate.
Pseudo steady state

\[ N_i = k_i (C_i - C_{i,\infty}) \]  
(7)

Calculation of average concentration in lollipop

\[ C_T = \frac{\rho_s V_s}{M_s} x_s + \frac{\rho_g V_g}{M_g} x_g \]  
(8)

\[ x_s = \frac{\rho_s V_s}{\rho_s V_s + m_g V_g} \]  
\[ x_g = 1 - x_s \]  
(9)

Concentration of sucrose and glucose in sugar layer (from solubility)

Sucrose solubility

\[ \frac{200g}{100mL\text{water}} = \frac{200g}{342.3g/mol} \]  
(10)

\[ y_s = \frac{n_{\text{sucrose}}}{n_{\text{sucrose}} + n_{\text{water}}} = 0.095; \ y_g = 0.083 \]

Substitute all values into the equation

\[ k_s (C_s - 0)4\pi R^2 + k_s (C_g - 0)4\pi R^2 = 4\pi R^2 \left( \frac{\rho}{M} \right)_{ave} \frac{dR}{dt} \]

Solve the equation, we have relation between time and R

\[ t = \frac{4D}{\nu} \left( \frac{D_s}{\rho_s} \right)^{1/3} C_s + \frac{4D}{\nu} \left( \frac{D_g}{\rho_g} \right)^{1/3} C_g \times R^2 \]

Conclusion

Set Vs:Vg=1:1/2, tabulate the t for R from 1cm to 3.5cm

<table>
<thead>
<tr>
<th>R (cm)</th>
<th>T( min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.96022</td>
</tr>
<tr>
<td>1.1</td>
<td>22.94187</td>
</tr>
<tr>
<td>1.2</td>
<td>27.30272</td>
</tr>
<tr>
<td>1.3</td>
<td>32.04277</td>
</tr>
<tr>
<td>1.4</td>
<td>37.16203</td>
</tr>
<tr>
<td>1.5</td>
<td>42.6605</td>
</tr>
<tr>
<td>2</td>
<td>75.84088</td>
</tr>
<tr>
<td>2.5</td>
<td>118.5014</td>
</tr>
<tr>
<td>3</td>
<td>170.642</td>
</tr>
<tr>
<td>3.5</td>
<td>232.2627</td>
</tr>
</tbody>
</table>

The radius of 1.2-1.3 cm of lollipop will give a consumption time of around 30 minutes. The real product size of lollipop is about 2.7 cm diameters for Chupa Chups brand lollipop which meets the requirement of their customers to have a 20-minute consuming time (only licking and no crash of it). The best optimized time depends on people’s fulfillment and marginal pleasure changing with time which can be done by survey the targeting customers. The manufacturer can also increase diameter of the lollipop if they want the consumer to enjoy more time on individual lollipop.
[IRON MAN, STRANDED!! ]

Iron Man lies in the freezing tundra of Antarctica, battered and bruised from the recent battle. “You might have won the battle, but you haven’t won the war Stane,” he groaned in a metallic modulation, while heaving a sigh of relief that he survived the blast of the AR-130 missile.

His internal computer system groans to a restart and indicates to him that while his suit is fully functional; his Arc Reactor battery has been damaged from the blast and requires immediate replacement. Iron Man painstakingly reaches down to his legs and opens the compartment containing various Arc Reactor battery replacements.

In the compartment storage unit, which stores the batteries safely at a temperature of 113K, he finds 3 usable replacements:

1. Platinum Battery (Cube) – Length = 7cm
2. Platinum Battery (Sphere) – Diameter = 8cm
3. Platinum Battery (Cylinder) – Length = 10cm, Diameter = 7cm

However, Iron Man is now faced with a dilemma. While these batteries are working, they require a core temperature of 345K in order to power up his metallic suit and to keep his life support unit going.

Iron Man’s backup power unit activates, indicating that he only has 6mins left to live. What he has to do now is to choose the battery with the geometry such that within 6mins of placing this battery inside the suit’s heating unit (h=100 W/m²K), it will be heated to the minimum operational core temperature of the battery of 345K. So which one does he choose? Will Iron Man live?
**Assumptions**

This is an unsteady state problem. The arc reactor batteries are assumed to be of solid platinum with the stated geometries. The initial battery temperature, $T_o = 113K$. The uniform oven (suit heating unit) temperature, $T_\infty = 473K$

**Calculations**

Following parameters are established at the average temperature (293K) within Iron Man’s suit.

<table>
<thead>
<tr>
<th></th>
<th>Cubic Battery</th>
<th>Spherical Battery</th>
<th>Cylindrical Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of platinum, $\rho$</td>
<td>$2.15 \times 10^4$ kg/m$^3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat capacity of platinum, $c_p$</td>
<td>$1.340 \times 10^2$ J/kg.K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Convective Heat Transfer coefficient of medium within the oven, $h$</td>
<td>100 W/m$^2$.K</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

First we calculate the Biot Modulus for each of the geometries using the equation $Bi = \frac{hV}{kA}$.

<table>
<thead>
<tr>
<th>V/A</th>
<th>Cubic Battery</th>
<th>Spherical Battery</th>
<th>Cylindrical Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biot Modulus</td>
<td>0.01663</td>
<td>0.01897</td>
<td>0.01849</td>
</tr>
</tbody>
</table>

Since the values for the Biot Modulus for all geometries are $\leq 0.1$, we will use the lumped parameter analysis for our calculations.

From lumped parameter analysis: $T = \frac{(T_0-T_\infty)}{\left[\exp \left( \frac{ht}{\rho c_p V}\right) \right]} + T_\infty$

Inserting all known values for $t = 6\text{mins} = 360\text{seconds}$, the uniform temperature of the batteries are tabulated below.

<table>
<thead>
<tr>
<th>Central Temperature, $T$</th>
<th>Cubic Battery</th>
<th>Spherical Battery</th>
<th>Cylindrical Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>349.65K</td>
<td>335.70K</td>
<td>331.976K</td>
<td></td>
</tr>
</tbody>
</table>

From our analysis, Iron Man will survive, but only if he choses the cubic shaped battery as it is the only geometry that would be able to reach the required operational temperature of 345K within 6 minutes. However, the exact time required for the cubic battery to reach 345K is 5.79 minutes. This renders Iron Man around 0.21 minutes or 12.6 seconds to make his decision. Considering the fact that Iron Man (Mr Tony Stark) is a engineering genius, we will assume that 12 seconds is adequate for him to pick out the correct battery. Mr Stark would also be advised to completely remove both of the less effective variants to prevent a repeat of this dilemma in case of future mishaps.
CN2125 Heat and Mass Transfer Mini Project
Rib-eye Steak Cooking Time

State Student Names and Matriculation Number Here
Jason, a guy who is keen to be a chef, decided to come out with a recipe of making rib-eye beef steak. Time for different degree of cooking was calculated by him after a thorough research on beef compositions, core temperature for different degree of cooking and other related information.

Core temperature for different degree of cooking is summarized below:

<table>
<thead>
<tr>
<th>Degree of Cooking</th>
<th>Raw</th>
<th>Medium Raw</th>
<th>Medium</th>
<th>Medium Well</th>
<th>Well Done</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Temperature</td>
<td>125°C</td>
<td>130°C</td>
<td>140°C</td>
<td>150°C</td>
<td>160°C</td>
</tr>
</tbody>
</table>

Table 1. Degree of cooking and the corresponding core temperature

To simplify the model, calculations are based on the following assumptions:
1. The shape of rib-eye steak is a cylinder. Usually dimension of the steak is 0.1m in diameter tabulated as D and 0.03m in thickness tabulated as H.
2. The steak will not shrink during cooking;
3. The cooking process is an one-dimensional heat transfer;
4. The convective heat transfer coefficient, \( h \) is obtained from literature as 15W/m²K (INCROPERA F.P. & DEWITT D.P., 2007).
5. The steak is flipped so frequently during cooking that there is no heat loss and property change on the uncooked side when the other side is in contact with the pan surface.
6. During calculation, we assume symmetric and simultaneous heating from both sides. The actual time needed is twice the time calculated. The heat is transferred only in the axial dimension of the cylindrical steak.
7. Initial temperature for beef is set to be \( T_0 = 10°C \); pan temperature, \( T_{pan} = 300°C \);
8. The specific heat capacity of the steak above freezing, \( c_p = 2.81kJ/kg·K \)
9. The conductivity of the steak is calculated using model proposed by R.G.M. van der Sman, from Agrotechnology and Food Sciences, Wageningen University based on its composition.

<table>
<thead>
<tr>
<th>Weight Percent</th>
<th>Fat</th>
<th>Protein</th>
<th>Water</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density(kg/m³)</td>
<td>0.9</td>
<td>1.35</td>
<td>1</td>
<td>1.057</td>
</tr>
<tr>
<td>Conductivity(W/mK)</td>
<td>0.222</td>
<td>0.410</td>
<td>0.633</td>
<td>0.669</td>
</tr>
</tbody>
</table>

Table 2: Composition of a rib-eye steak and its conductivity

The conductivity of the steak is given by (R.G.M. van der Sman, 2007):

\[
k_{\text{con}} = k_{\text{concon}} \frac{1 + (\epsilon_{\text{condis}}/\epsilon_{\text{con}} + \epsilon_{\text{condcon}}/\epsilon_{\text{con}} (1 - 2Q_{\text{con}}))\delta_{\text{con}}}{1 + \epsilon_{\text{concon}}/\epsilon_{\text{con}}(1 - 2Q_{\text{con}})\delta_{\text{con}}}
\]

Where, \( \epsilon_{\text{con}} = \epsilon_{\text{condcon}} + \epsilon_{\text{condis}} \)
\( \epsilon_{\text{con}} \), is volume fraction of the continuous phase. Assuming beef is of one continuous phase, \( \epsilon_{\text{con}} = 1 \) in this case.
\( \epsilon_{\text{concon}}, \epsilon_{\text{condis}} \) are volume fraction of unfrozen solution, water, in this case, and insoluble , fat and protein, in this case, respectively.

In meat emulsion, \( Q_{\text{con}} = \frac{1}{3} \). The effective conductivity of the insoluble (fat and protein), \( k_{\text{condis}} = (\epsilon_{f}k_{p} + \epsilon_{p}k_{f})/ \epsilon_{\text{condis}} = 0.742 \) (where, \( \epsilon_{\text{condis}} = \epsilon_{f} + \epsilon_{p} = 34.46\% \))
And, \( \delta_{\text{con}} = \frac{k_{\text{condis}} + k_{\text{concon}}}{k_{\text{concon}}} = 0.1725 \) (where \( k_{\text{concon}} = k_{\text{water}} \))

Conductivity is calculated as 0.669.

Cooking the steak is actually an unsteady conduction process of a cylinder. To find out the time it will take to achieve a certain core temperature (i.e., the temperature at the symmetry center), Heissler Charts can be used.

Take cooking raw steak, core temperature after cooking, \( T = 125^\circ C \), as an example.

Calculation of the three dimensionless ratios:

<table>
<thead>
<tr>
<th></th>
<th>Unaccomplished temperature change, ( Y = \frac{T_{\text{pan}} - T}{T_{\text{pan}} - T_0} )</th>
<th>= 0.603;</th>
<th>Relative position, ( n = \frac{x}{x_1} = \frac{0}{0.015} = 0 ); ( (x_1 = H/2 = 0.015m) )</th>
<th>Relative resistance, ( m = \frac{k}{h x_1} = \frac{0.669}{15 \times 0.015} = 2.9733 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Read from Appendix F in the textbook, the relative time, ( X = \frac{\alpha t}{x_1^2} = 2.15 ).</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The thermal diffusivity of the steak, \( \alpha = \frac{k}{c_p \rho} = \frac{0.669}{2810 \times 1057} = 2.25 \times 10^{-7} \) m²/s

Thus, \( t = \frac{x x_1^2}{\alpha} = \frac{2.15 \times (0.015)^2}{2.25 \times 10^{-7}} = 2150s = 35.83\)min

The cooking time for raw cooked steak, time = 2t = 71.6 min

Similar calculation can apply on medium raw, medium, medium well and well done cooked steak. The results are tabulated as below:

<table>
<thead>
<tr>
<th></th>
<th>( Y )</th>
<th>( n )</th>
<th>( m )</th>
<th>( X )</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td>0.603</td>
<td>0</td>
<td>2.973</td>
<td>2.15</td>
<td>71.6</td>
</tr>
<tr>
<td>Medium Raw</td>
<td>0.586</td>
<td>0</td>
<td>2.973</td>
<td>2.35</td>
<td>78.2</td>
</tr>
<tr>
<td>Medium</td>
<td>0.552</td>
<td>0</td>
<td>2.973</td>
<td>2.60</td>
<td>86.6</td>
</tr>
<tr>
<td>Medium Well</td>
<td>0.517</td>
<td>0</td>
<td>2.973</td>
<td>2.75</td>
<td>91.6</td>
</tr>
<tr>
<td>Well Done</td>
<td>0.483</td>
<td>0</td>
<td>2.973</td>
<td>2.90</td>
<td>96.6</td>
</tr>
</tbody>
</table>

*Table 3. results for five degrees of cooking steak*

Thus in conclusion, to cook a normal size rib-eye beef steak, cooking time ranges from 71.6 minutes to 96.6 minutes in order to achieve different degrees of cooking. Using the methods tabulated above, the cooking time for different sizes of rib-eye steak and different types of beef steaks can all be calculated. The theoretically calculated time is a good reference for new learners to control the degree of cooking for the beef steaks.

**Reference**


Problem Statement:
In 2007, there were about 8000 dengue cases and 20 dengue fatalities in Singapore. Aedes mosquitoes are the root cause of spreading dengue, thus to prevent the spread of dengue, the National Environment Agency (NEA) advocates the prevention of the breeding of Aedes mosquitoes. One of the methods NEA recommends to eradicate the breeding grounds of Aedes mosquitoes, is to introduce prescribed amount of granular insecticide into places where stagnant water (potential breeding ground of mosquitoes) is unavoidable or difficult to remove.

The granular insecticides, as recommended by NEA, have 1% Temephos as their active ingredients. NEA recommends that the insecticides to be added once a month as its effectiveness against mosquitoes can last for 1 month (30 days). In this report, we want to determine the size of the granular that can maintain the desired mortality effectiveness for 1 month.

Modeling the Diffusion of Temephos in Water Medium
The transient diffusion of Temephos in water medium occurs at constant temperature and pressure of 298.15K and 101325 Pa respectively. The granular insecticides, assumed to be spherical, has initial Temephos concentration of 1ppm, are placed in 1L of larvac-infested water. Considering a limiting case where the resistance of the film mass transfer of the Temephos through the liquid boundary layer surrounding the granular is negligible, so \( k_c = 0 \). Also, it is assumed that the Temephos is immediately carried away and consumed to eradicate the mosquitoes once it reaches the bulk medium, so \( C_{AS} = 0 \)ppm. It is desired to have at least 0.012ppm (Carvalho 2004) of Temephos in the centre of the granular to achieve an 98% effective mosquito mortality.

Solution:
First, it is necessary to calculate the diffusivity of Temephos (specie A) in a water medium (specie B). Temephos is an organic insecticide and a non-electrolyte molecule in water so the Wilke-Chang correlation is a suitable equation to calculate \( D_{AB} \).

Temephos has a molecular formula of \( C_{16}H_{20}O_6P_2S_3 \). At normal boiling point, the molecular volume of Temphos can be evaluated below:

\[
V_C = 14.8\text{cm}^3/\text{mol} \quad V_H = 3.7\text{cm}^3/\text{mol} \quad V_O = 7.4\text{cm}^3/\text{mol} \\
V_P = 17.0\text{cm}^3/\text{mol} \quad V_S = 15.5\text{cm}^3/\text{mol} \quad \text{Correction (2 benzene rings)} = 30.0\text{cm}^3/\text{mol}
\]

Hence, \( V_A = (16)(14.8)+20(3.7)+(6)(7.4)+(2)(17.0)+(3)(15.5)-30 = 405.7\text{cm}^3/\text{mol} \)

\( V_A \) is found to be 405.7cm\(^3\)/mol. Molecular weight of water, \( M_B \) is 18.0g/mol. Viscosity of water, \( \mu_B \) is 1.45cp. The association parameter of water, \( \Phi_B \) is 2.26. The temperature of the solution, \( T \) is 298.15K. Substituting the above values into the Wilke-Chang correlation, we obtained:

\[
\frac{D_{AB}\mu_B}{T} = \frac{7.4 \times 10^{-8}}{V_A^{0.6}} (\Phi_B M_B)^{\frac{1}{2}}, \quad D_{AB} = 2.64 \times 10^{-6} \text{cm}^2/\text{s}
\]
For the transient diffusion of Temephos in water medium, the Hessler’s Chart may be employed. The boundary conditions are:

\[ C_A = C_{A0} = 1 \text{ ppm} \quad \text{at } t=0 \quad \text{for } 0 \leq r \leq R \]

\[ C_A = C_{AS} = 0 \text{ mg/mg} \quad \text{at } r=0 \quad \text{for } t \geq 0 \]

\[ C_A = C_{AS} = 0 \text{ mg/mg} \quad \text{at } r=R \quad \text{for } t \geq 0 \]

| Dimensionless ratio, \( Y = \frac{C_{AS}-C_A}{C_{AS}-C_{A0}} = \frac{0-0.012}{0-1} = 0.012 \) |
| Relative time, \( X = \frac{tD_{AB}}{x_1^2} = \frac{2.64 \times 10^{-6} \text{ cm}^2 \text{s}^{-1} \times 30 \text{days} \times 24 \text{hr} \times 60 \text{min} \times 60 \text{s}}{x_1^2} \) |
| Relative position, \( n = \frac{x}{x_1} = 0 \) |
| Relative resistance, \( m = \frac{D_{AB}}{kx_1} = 0 \), convective resistance is negligible |

From Appendix F, Figure F.3, the corresponding value of \( X \) is 0.55.

\[ X = \frac{tD_{AB}}{x_1^2} = \frac{2.64 \times 10^{-6} \text{ cm}^2 \text{s}^{-1} \times 30 \text{days} \times 24 \text{hr} \times 60 \text{min} \times 60 \text{s}}{x_1^2} = 0.55 \]

\( \therefore \) radius of granular = \( x_1 = 3.53 \text{ cm} \)

**Discussion of Results:**

It has been found that the minimum radius should be 3.53cm. However, most commercially available granular insecticides is less than 1cm diameter, thus they will not last for 1 month. This discrepancy can be due to that we have taken the mosquito mortality effectiveness to be 98%, while the commercially accepted effectiveness may be less than 98%. We have also assumed that all there is \( C_{AS} = 0 \) and convective resistance is negligible, however in reality, there may be residual Temephos present in the bulk medium and there is significant surface resistance.

**Conclusion:**

Thus, in order to allow the insecticide to last for 1 month, it can be suggested that the granular insecticides be packed into spherical sachet of 3.53cm in radius, assuming that mass transfer only occurs at the exterior surface of the satchet. In fact, a similar approach has already been adopted by the Singapore Arm Forces (SAF) in the military camps, and it was reported that this helped to save SAF an estimated of $178000 annually (Mindef).

**Reference:**


