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Review Article

Transportation Process of Alcohol in the Human Body System

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Abstract

Diffusion is the term used to describe the random motions of molecules that causes a material to move through a system. The purpose of this work is to examine the model behaviour of alcohol diffusivity in the human stomach wall. The mathematical models from fick's second law were used to describe the movement of alcoholic concentrations from the stomach to the bloodstream over distance, r and time, t as blood solution moves at constant velocity through the blood vessel. The models for the diffusion process in human bloodstream were solved both analytically and numerically and were simulated in MATLAB® v2016b. Three students (A, B and C) were used as case study. For Student A, the concentration inside the stomach decreases over time but with and initial increase before decreasing in the stomach lining. In student A's stomach, concentration in the spherical stomach decreases much more rapidly than the concentration in the cartesian system. For student B, the concentration of the stomach increases everywhere and eventually levels off when it reaches steady-state. Student C is similar to student A. Multiple impulses were applied to the system in order to simulate his periodic drinking behavior or drinking pattern and it was observed that there is similarity with student A except that concentration profile for student C oscillates due to the sine term which causes the concentration to slightly increase at each point in time, then decrease.

Keywords: Diffusion; Mathematical models; Human stomach; Concentration profile; Alcohol; MATLAB®

Introduction

The dependence of life processes on diffusion systems could not be more prevalent. Physiological diffusion (e.g. drug absorption, exchange of gases, nutrient uptake, alcohol consumption, etc.) occurs may occur by the absorption of intake through the stomach lining into the bloodstream, or it can continue on to the small intestine, where it can again be absorbed into the bloodstream [1,2].

Unwanted fluids can be absorbed from the stomach or by inhalation in the lungs, distributed throughout the body fluids and tissues via the blood, eliminated only slowly via the lungs, kidneys, and skin, and removed chiefly by slow metabolic oxidation [1-4].

Alcohol kills in traffic related accidents five times more people than cocaine, heroin, marijuana and all the other illegal drugs together [5]. Given the growth of current consumption between our youth and societies, there are misconceptions about the level of alcohol that results from specific patterns of consumption, due to the lack of information.

When ethanol (alcohol) is consumed, the liquid first enters the stomach. Alcohol in the stomach can be absorbed through the stomach lining into the bloodstream, oritcancontinueontothesmallintestine, where it can again be absorbed into the bloodstream. Intoxication occurs after absorption into the bloodstream, due to the presence of alcohol in the blood. Although alcohol can really be absorbed into the bloodstream at any point along the gastrointestinal digestive tract from the mouth during ingestion to the small intestine, the majority of the alcohol enters the bloodstream via either the stomach lining or the small intestine walls [6]. Approximately 20% of ethyl alcohol consumed is absorbed in the sto mach and 80% is absorbed in the small intestine [6], while a negligible amount is absorbed in the remainder of the digestive tract.

The difference between absorption in the stomach and the intestine is due to the difference in surface areas that limits diffusion rates ($0.045m^2$ is the surface area of the stomach, $600m^2$ is the surface are of the small intestine). Because more alcohol is absorbed in the small intestine than in thes to mach, most alcohol absorption studies have traditionally studied, simulated, or experimentally measured the changing rate of alcohol concentration in the blood or the breath and compared that to the rate of gastric emptying into the small intestine [7]. The rate of alcohol absorption over all is depend entone the rate of as tric emptying since alcohol absorption occurs primarily from the small bowel [3]. Thus, most studies testing breathanalyzers typically use this relationship to determine the accuracy of the breathalyzer, a device that measures Breathe Alcohol Content (BrAC), which is in turna fraction of Blood Alcohol Content (BAC), which provides a quantification of intoxication. Typical profile of alcohol in the blood following as hort period of drinking then stopping resembles a bell curve. It is difficult to pinpoint the exact BAC back in time, and to determine exactly where the person was on the bell curve at the time of driving. However, this process would involve considering exactly what drink was consumed, exactly what time drinking occurred, and quantifying alcohol absorption into the bloodstream through both the stomach and the small intestine. In this study, we investigated the

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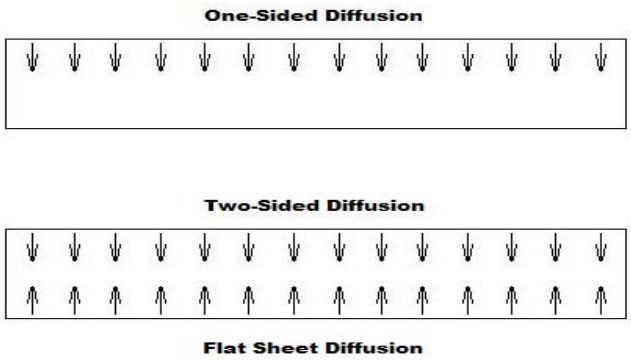

Figure 1: Schematic of Diffusion through a Flat Sheet.

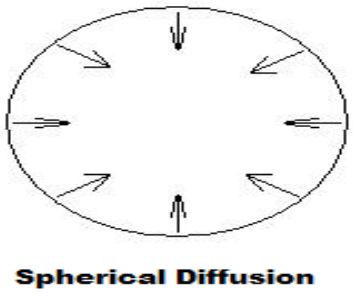

Figure 2: Schematic of Diffusion through a Sphere.

model of absorption of alcohol through the stomach lining in order to determine how much of blood alcohol content is due to absorption in the stomach alone. We also use this approach to model further the changing concentration of alcohol absorbed in the stomach as a person's drinking behavior changes over time.

Mathematical Model

To model the transport of alcohol through the stomach, analytical and numerical computational solutions were provided. Three case (A, B and C) models of equal concentration of alcohol intake were used and compared for the prediction of the metabolism.

The three cases decided to go to a bar for a drink. A goes down on beer and drinks until his stomach is full. He then realizes he needs to drive, and stops drinking immediately. B decides to go all out, and can be found constantly slowly drinking beer. C's drinking pattern is consistent throughout the night. He drinks beer, then drinks water, drinks beer, then drinks water, and so forth throughout the night.

Model Assumptions

- Within a particular blood vessel, the speed of blood flow is taken as constant.
- The radius of the blood vessels is also constant.
- There exists a mechanism that instantaneously removes the diffused substrate from the tissue fluid into the cells thereby maintaining constant.
- Diffusion alone is able to account for the differences in the concentration of the substrate in the entrance and exit of the section under consideration.

Model the concentration of alcohol at the outer edge of the stomach over time for each of the cases. To determine the concentration profile over time at the center of the stomach, at the inner lining of the stomach, and the outer lining of the stomach. Diffusion in the stomach walls can be modeled by using Fick's 2nd Law of diffusion in one dimension in Cartesian coordinates where C is concentration, t is time, x is position, D is diffusivity, and Q denotes a driving force (Figure 1).

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} \qquad (1)$$

D is known as the diffusivity or diffusion coefficient and is usually reported in units of m^2/s or cm^2/s.

The stomach can be assumed to be roughly spherical; Fick's 2nd Law of diffusion in three dimensions in spherical coordinates would be more accurate.

$$\frac{\partial C}{\partial t} = D\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial C}{\partial r}\right)+ \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial}{\partial\theta}\right)+\frac{1}{r^2\sin^2\theta}\frac{\partial^2 C}{\partial\phi^2}\right] \qquad (2)$$

Assuming constant mixing (spherical symmetry) in the stomach in order to approximate this as a one dimensional problem.

$$\frac{\partial C}{\partial t} = D\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial C}{\partial r}\right)\right]+Q \qquad (3)$$

The diffusing material is traveling directly into the sphere along the radial lines of the sphere so that the pathway of diffusion is just the radius of the sphere seen in Figure 2.

The stomach normally holds a volume of about 1liter (Hypertext book). A sphere with a radius of about 6cm would have this volume. The stomach wall has a thickness of 0.51±0.11 cm (Rapaccini, etal.1988). Therefore, we approximated the stomach as a sphere with an outer radius of 6.5cm and an inner radius of 6.0cm to account for a 0.5cm thick wall.

We only seek to keep the concentration the same throughout the stomach. It should be noted here that we are only considering diffusion through the stomach wall itself. However, there is volume/space inside the stomach itself. In order to accomplish this, we assume that the diffusivity yin the volume of the stomach or in the stomach chamber from the center of the stomach to the inner edge of the wall is extremely high: $1015cm^2/s$. This for her inside of the stomach to be well mixed and does not allow the concentration to varies with position inside the stomach volume. Finally, we can approximate the diffusivity of alcohol in these to mach wall to be 10-4 cm^2/s.

This equation is only valid under certain assumptions. The first is that diffusion takes place only in the dimension of the thickness. The other dimensions must be large enough with respect to the thickness so that they are comparably infinite in size. Therefore diffusion in those directions has a small enough effect to be considered negligible. The composition and thickness of the material must both be uniform. Finally, the diffusion pathway is assumed to follow direct paths along the thickness of material.

Diffusion through a flat sheet may be either one- or two-sided. If the diffusing material enters and moves through the polymer from

Table 1: Student A.

Diffusion Equation:	Initial Conditions:	Boundary Conditions:
$\frac{\partial C}{\partial t} D\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial C}{\partial r}\right)\right]$	C(r<6 cm, t=0)= 0.05 C(r<6 cm, t=0)=0	$\frac{\partial C}{\partial r}(r=0,t)=0$ C(r=6.5 cm, t) = 0
$\frac{\partial C}{\partial t}=D\frac{\partial^2 C}{\partial x^2}$	C(r<6 cm, t=0)= 0.05 C(r<6 cm, t=0)=0	$\frac{\partial C}{\partial r}(r=0,t)=0$ C(r=6.5 cm, t) = 0

only one surface of the sample it is considered one-sided. On the other hand, if the diffusing material comes in contact with the polymer on both sides of the sheet, the diffusion is considered two-sided.

Alcohol diffusion through the stomach wall of Student A is model Cartesian coordinates and spherical coordinates for comparison. Alcohol diffusion through thes to mach walls of Student Band Student C are modeled in spherical coordinates.

The stomach walls of students A, B and C all have the same boundary conditions:

$$\left.\frac{dC}{dr}\right|_{r=0}=0 \qquad (4)$$

C(r=0) =0

The first boundary condition makes it so the concentration profile is continuous and differentiable at the center of the sphere.

The second boundary condition forces the concentration to go to zero (0) as the alcohol leaves the stomach and enters the bloodstream. Here, it is assumed that the volume of the bloodstream is much larger than the stomach. This is not a completely unreasonable assumption given that the stomach volume is approximately 1L and total blood volume is approximately 5L.

Initial Conditions and Driving Forces

Student A

Student A drank until his stomach was full of beer at time = 0. The initial conditions for this problem set the concentration to 0.05 alcohol by volume (ABV) inside the stomach volume (0 < r < 6cm) and to 0 in the stomach wall (6cm < r <6.5cm). There is no driving force (Table 1).

Student B

Student B started off with no beer in his stomach. The initial conditions for this problem set the concentration to 0 everywhere. The person started drinking at a slow, constant rate. The driving force is modeled as a constant function applied to inside of the stomach volume only (0 < r < 6cm). Once the stomach is full of beer, the concentration of alcohol in the stomach cannot further surpass the concentration of alcohol in beer (Table 2).

Student C

Student C also drank until his stomach was full of bee rat time=0. The initial conditions for this problems at the concentration to 0.05 AB Vin side the stomach volume (0<r<6cm) and to 0 in the stomach wall (6cm<r<6.5cm). The person had a drink of beer, then a drink of water, then a drink of beer, and a drink of water, and so forth. The driving force can be modeled by a sine squared function applied to inside of the stomach volume only (0<r<6cm). Each time he drinks beer, he is on the increasing part of the function. Each time hed rinks water, he is on the decreasing part of the function (Table 3).

Analytical solution

$$\frac{\partial C}{\partial t}=D\frac{1}{r^2}\frac{\partial}{\partial r}r^2\frac{\partial C}{\partial r} \qquad (5)$$

C(r,t) =P(r)T(t) $P\frac{\partial T}{\partial t}=DT\frac{1}{r^2}\frac{\partial}{\partial r}r^2\frac{\partial P}{\partial r}$ (6)

$$\frac{1}{DT}\frac{\partial T}{\partial t}=\frac{1}{\Pr^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial P}{\partial r}\right);\ \frac{1}{DT}\frac{\partial T}{\partial t}=\frac{1}{\Pr^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial P}{\partial r}\right)=-\lambda^2 \qquad (7)$$

Both sides of the above quationare in dependent. Thus for them to be equal, they must both be equal to a constant. Solving each side separately:

$$\frac{\partial T}{\partial t}=-\lambda^2 DT\Rightarrow T(t)=Ae^{-\lambda^2 DT} \qquad (8)$$

$$\frac{\partial}{\partial r}\left(r^2\frac{\partial P}{\partial r}\right)=-\lambda^2 r^2 P \qquad (9)$$

Substitution with x=λr=>dx=λdr

$$\frac{\lambda\partial}{\partial x}\left(\frac{x^2}{\lambda^2}\lambda\frac{\partial P}{\partial r}\right)=-x^2P;\qquad x^2\ddot{P}+2x\dot{P}+x^2P=0 \qquad (10)$$

Let k = 0, $x^2\ddot{P}+2x\dot{P}+\left[x^2+k(k+1)\right]P=0$

the solution sare Bessel functions, but k = 0. Thus,

$$P(x)=B_1\frac{\sin x}{x}+B_2\frac{\cos x}{x}$$

$$P(r)=B_1\frac{\sin\lambda r}{\lambda r}+B_2\frac{\cos\lambda r}{\lambda r} \qquad (11)$$

(12)

$$C(r,t)=\left(C_1\frac{\sin\lambda r}{\lambda r}+C_2\frac{\cos\lambda r}{\lambda r}\right) \qquad (13)$$

Apply Boundary Conditions:

$$\frac{\cos\lambda r}{\lambda r}(r=0)\ \text{Is discontinuous}\ \therefore C_2=0 \qquad (14)$$

$$C(R,t)=0=C_1\frac{\sin\lambda R}{\lambda R}e^{-\lambda^2 DT} \qquad (15)$$

$$\lambda R=n\pi\Rightarrow\lambda=\frac{n\pi}{R}\ \text{ for n=1, 2, 3…} \qquad (16)$$

$$C(r,0)=\begin{cases}C_0, r<R-w\\ 0, r>R-w\end{cases} \qquad (17)$$

For: r<R-w:

$$C_0=\sum_{n=1}^{\infty}C_n\frac{\sin\frac{n\pi r}{R}}{\frac{n\pi r}{R}}e^0 \qquad (18)$$

Numerical solution

The MATLAB built in pdepesolver was used to numerically approximate the solutions modeling A, B, and C. Code and plots are attached for each of the three cases. A was modeled in both spherical and Cartesian coordinates in order to show the effect hat the coordinate systems have on the concentration profiles. Band C were modeled only in spherical coordinates.

Table 2: Student B.

Diffusion Equation:	Initial Conditions:	Boundary Conditions:
$\frac{\partial C}{\partial t}D\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial C}{\partial r}\right)\right]$ Q(r<6 cm)=0.0187 Q(r<6 cm)=0	C(r<6 cm, t=0)=0 C(r<6 cm, t=0)=0	$\frac{\partial C}{\partial r}(r=0,t)=0$ C(r=6.5 cm, t)=0

Table 3: Student C.

Diffusion Equation:	Initial Conditions:	Boundary Conditions:
$\frac{\partial C}{\partial t} D\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial C}{\partial r}\right)\right]$ Q(r<6 cm)=0.01 $\sin^2(\pi t)$ Q(r<6 cm)=0	C(r<6 cm, t=0)=0.05 C(r<6 cm, t=0)=0	$\frac{\partial C}{\partial r}(r=0,t)=0$ C(r=6.5 cm, t)=0

Matlab boundary conditions and initial conditions

Driving for cesandinitial conditions were implemented in MATLAB using if/else statements. Homogeneous bound ray conditions were implemented in MATLAB using typical deep methods as shown in the code below.

Results and Discussion

For Student A, the concentration inside the stomach is initially 0.05 and the concentration in stomach lining is initially 0. The concentration inside the stomach decreases overtime. Threat at which the concentration decreases does not depend on position within the stomach volume inside the inner wall. However, this is not the case for the stomach lining. The concentration in the stomach wall initially increases, and then even tually decreases overtime.

The concentration depends on the position within the stomach lining. The solution makes physical sense, as the system begins with a fixed concentration of ethanol, and no additional ethanol is added to the system.

Eventually, all of the ethanol should diffuse out the stomach into the bloodstream. The plots for Student A's stomach also show a difference between the two coordinate systems. The concentration in the spherical stomach decreases much more rapidly than the concentration in the Cartesian system (Figure 3). This is expected because the spherehasa greater surface area to diffuse through.

The concentration will approach zero much sooner in the spherical system as opposed to the Cartesian system (Figure 4). This highlights the importance of being able to model the spherical coordinate system. For student B, the concentration is initially 0 everywhere. A constant driving for ceisapplied to the system in order to simulate Student B's constant drinking. The concentration of the stomach increases everywhere and even tually levels off when it reaches steady-state. The steady-state con centration is depend. Student Dissimilar to Student A. With Student C, multiple impulses are applied to the system in order to simulate his periodic drinking behavior or drinking pattern.

This is modeled by using a driving force that is a squared sine function. The plot sarevery similar between Students A and except that concentration profile for student C oscillates due to the sine term. Student C's oscillating drinking pattern causes the concentration to slightly increase at each point in time, then decrease. This makes sense physically, as the student is repeatedly drinking beer, then diluting the concentration of alcohol in his stomach with water. Furthermore, the overall trend of the concentration profiles of Student A and C are similar; they both gradually decrease and level off. However, it takes longer for the concentration of alcohol in Student Cto reach 0, because he is still consuming more alcohol after time 0.

Conclusion

Future work could be conducted to make fewer assumptions. One

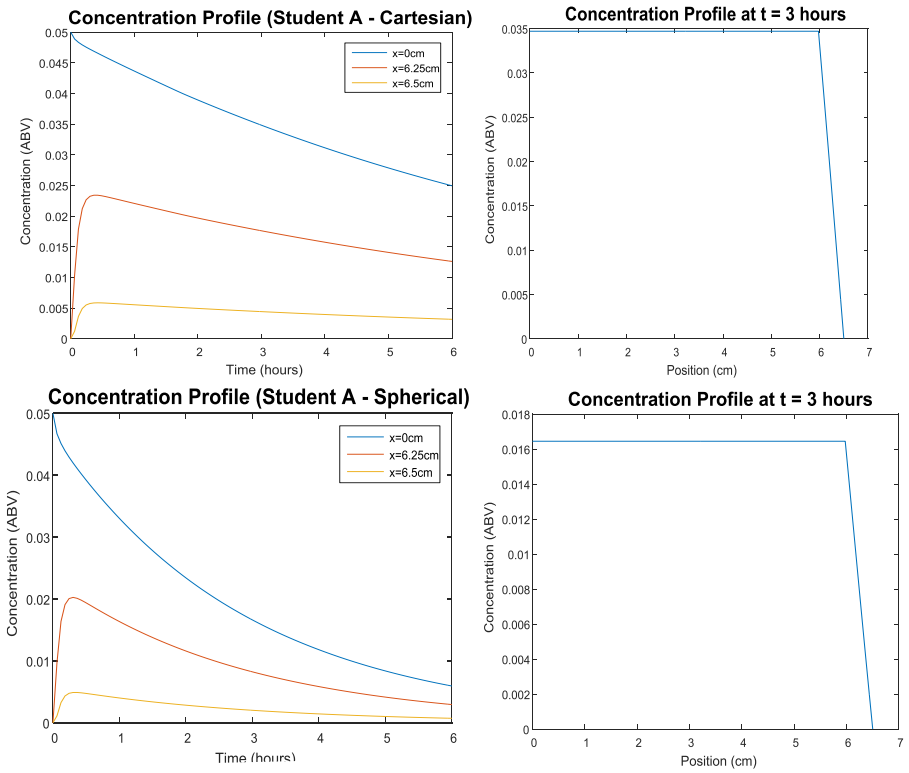

Figure 3: A. Cartesian Coordinates *VS* Spherical Coordinates (Student A).

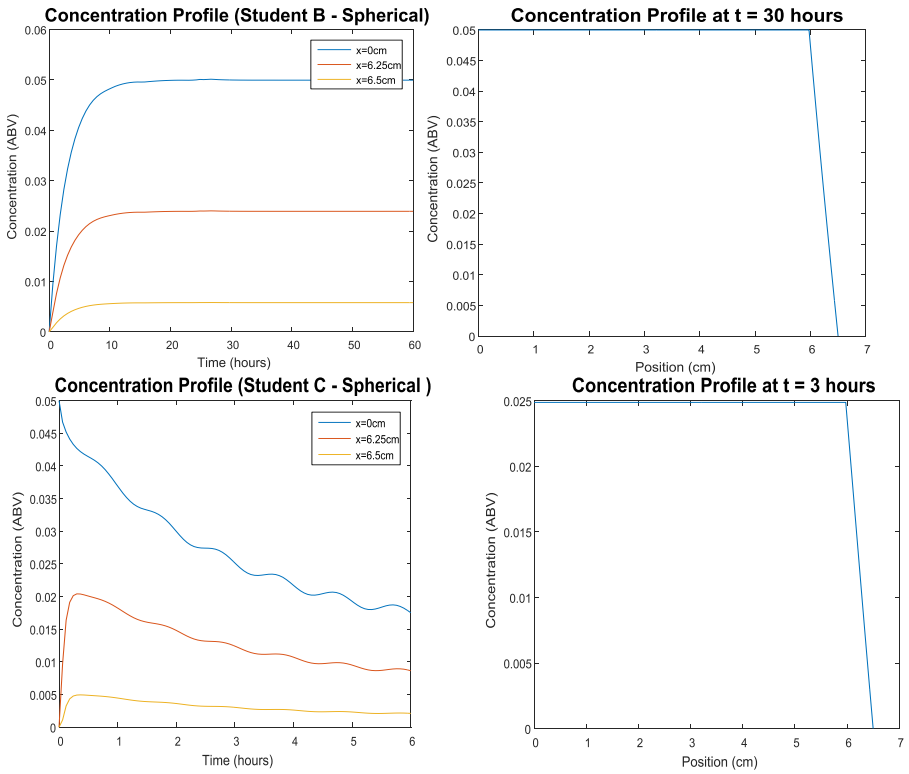

Figure 4: B. Spherical Coordinates (Student A, B, and C).

assumption was made in the initial condition that the concentration of the stomach is 0.05ABV. This assumes that person has only consumed beer with 0.05ABV, and thus, the person's stomach has only beerinit. We have neglected the presence of food as well as various stomach fluids. Our model could also take into account the other foods and beverages that the individual has consume din recent hours. An equation would have to be included for the initial condition. This equation would include variables for the amount of food and non-alcoholic beverages consumed. Another assumption that could be removed would be the shape of thes to mach. This problem assumes stomach with a spherical shape.

This is not true in actuality. However, it would be difficult to model a different shape in order to approximate a solution. A more accurate model would include gastric emptying into the small intestine.

A negative driving force term could be use dto simulate liquid moving from stomach to the small intestine. A differential equation modeling absorption from the small in testing could be coupled to this model of the stomach in order to determine overall alcohol absorption in to the bloodstream. This would allow for Blood Alcohol Content (BAC) to be determined. Then this problem could be expanded to determine is suessuc has at what time the students would be safe to drive, or would be considered no longer intoxicated.

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