Choose Focus Analysis

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Inspiration for the topic

My mother would always counsel not to eat fast foods. Being a daddy’s girl, I didn’t pay heed to her words. After a grave experience I realized how detrimental the fast foods are. Being the eldest granddaughter of my joint family I advise the same to my cousins. But when they pester sometimes for fast foods I don’t know how I arrive at innovative ideas to metamorphose their melancholic smile to a genuine smile. Then onwards they rush to my home during my holidays. I prepare mickey mouse dosas, pink idlis, bat ball shaped sweets etc for them. Decorating the dishes with vegetables and fruits will be fascinating and also helpful instead of fast foods. At the same time I feel so contented that I am learning cookery with newfangled ideas even after staying away from my joint family.

My cousins try to imitate me in my absence. Therefore I recommend them to cook in microwave as it is safer than the gas stove and achieved in less time.

I conceived to execute my CFA with mickey mouse dosa applying heat transfer principles.

Dosa recipe (1)

Ingredients

Rice : 4 cups
Urad dal(split black gram): 1 cup
Water : 1.25 cups

Method

- Soak 1 cup of urad dal for 3 hrs.
- Grind it adding water to smooth consistency.
- Then add 4 cups of rice.
- Let it ferment overnight.
- Make dosa of required shape on the pan and then microwave on 200^0C for 10 minutes.

Objective

I) to be acquainted with the types of heat transfer encountered.

II) to calculate the percentages of respective types of heat transferred.

III)cooking time estimation (theoretical) and comparing it with my experimental time.

Introduction

Heat is energy in transit. The transfer of energy as heat occurs at the molecular level as a result of a temperature difference. Heat is capable of being transmitted through solids and fluids by conduction, through fluids by convection, and through empty space by radiation.

Microwave cooking occurs as a result of volumetric thermal energy generation throughout the food, without heating of the food container or the oven wall. Conventional cooking relies on radiant heat transfer from the oven walls and/or convection heat transfer from the air space to the surface of the food and subsequent heat transfer by conduction to the core of the food. (2)

Morphological features of mickey mouse dosa

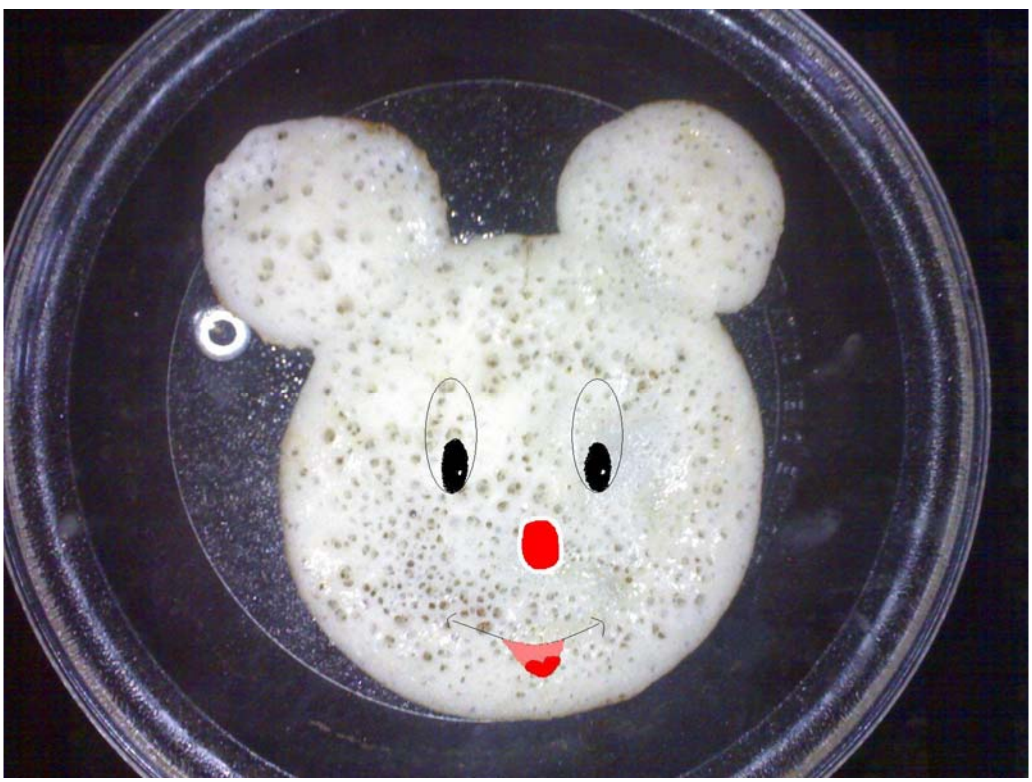
Radius of face : $\mathbf{r}_1 = 2.5$in

Radius of ear : $\mathbf{r}_2 = 1$in

Thickness : $\Delta\mathbf{x} = 0.005$cm

Total surface area of mickey mouse dosa : **A**

$$\mathbf{A} = \pi r_1^2 + 2(\pi r_2^2)$$
$$= 3.14*[(2.5)^2 + 2(1)^2]$$
$$= 25.9 \text{ in}^2 = 0.0166 \text{ m}^2$$



Calculations

I)

Total heat transferred heat transferred by radiation : $\mathbf{Q_t}$

$$\mathbf{Q_t = Q_r + Q_c + Q_h}$$

Radiation

Heat transferred by radiation : $\mathbf{Q_r}$

$$\mathbf{Q_r = A\varepsilon\sigma(T_1^4 - T_2^4)} \qquad (3)$$

Notation

$\mathbf{A}$ = total surface area of the body = 0.0166 m^2
ε = emissivity of the body = 0.9 (3)
σ = is the Stefan-Boltzmann constant = 5.73×10^{-8} J m^{-2} $s^{-1}K^{-4}$
$\mathbf{T_1}$ = the absolute temperature of the body = 200^0 C = 473.15K
$\mathbf{T_2}$ = the absolute temperature of the surroundings = room temperature = 22^0 C = 295.15K

$$\mathbf{Q_r} = A\varepsilon\sigma(\boldsymbol{T_1}^4 - \boldsymbol{T_2}^4)$$
$$= 0.0166*0.9*5.73 \times 10^{-8} *(473.15^4 - 295.15^4)$$
$$= 36.40 \text{ W}$$

Convection

Heat transferred by convection : $\mathbf{Q_c}$

$\mathbf{Q_c} = \mathbf{h_c} (\mathbf{T}_1 - \mathbf{T}_2)$ (3)

Calculation of $\mathbf{h_c}$

Natural convection about *planes*, such as oven walls (3)

$(Nu) = 0.53(Pr.Gr)^{0.25}$ for $10^4 < (Pr.Gr) < 10^9$

$(Nu) = 0.12(Pr.Gr)^{0.33}$ for $10^9 < (Pr.Gr) < 10^{12}$

For air these equations can be approximated respectively by:

$h_c = 1.3(\Delta T/L)^{0.25}$

$h_c = 1.8(\Delta T)^{0.25}$

Nusselt number $\mathbf{Nu} = \mathbf{h_c D/ k}$
Prandtl number $\mathbf{Pr} = \mathbf{c_p}\mu/\mathbf{k}$
Grashof number $\mathbf{Gr} = \mathbf{D}^3\rho^2\mathbf{g}\ \beta\ \Delta\mathbf{T}/\mu^2$

Properties of air at mean film temperature $(22 + 200)/2 = 111^0C = 384.15K$ (4)

- Density : $\rho = 0.9205672386605551\ kg/m^3$
- Specific heat : $\mathbf{c_p} = 1012.2474294457008$ Ws/kgK
- Viscosity : $\mu = 0.000021951821172833556$ kg/ms
- Thermal conductivity : $\mathbf{k} = 0.032422458438556165$ W/mK

$\mathbf{Pr} = \mathbf{c_p \mu / k}$

$= 1012.2474294457008 * 0.000021951821172833556 / 0.032422458438556165$

$= 0.685348231$

$\mathbf{Gr} = \mathbf{D}^3 \rho^2 \mathbf{g}\ \beta\ \Delta\mathbf{T}/\mu^2$

D = characteristic length = diameter = $\mathbf{D_1 + 2D_2}$

$\mathbf{D_1}$ = 5 in = 0.1269m

$\mathbf{D_2}$ = 2 in = 0.0507m

g = acceleration due to gravity 9.81 m/s^2

$\Delta\mathbf{T} = \mathbf{T}_1 - \mathbf{T}_2$ = 473.15 -295.15 =178 K

β = volumetric thermal expansion coefficient of air

$\mathbf{D = D_1 + 2D_2}$

$= 0.1269 + 2(0.0507)$

$= 0.2283$m

β at 100^0C $= 2.68*10^{-3}\ K^{-1}$ (5)

at 120^0C $= 2.55*10^{-3}\ K^{-1}$

By interpolation

β at 111^0C $= 2.6085*10^{-3}\ K^{-1}$

$\mathbf{Gr} = [\mathbf{D}^3 \rho^2 \mathbf{g}\ \beta\ \Delta\mathbf{T}]/\mu^2$

$= [(0.2283)^3 * (0.9205672386605551)^2 * (9.81) * (2.6085*10^{-3}) * (178)] / (0.000021951821172833556)^2$

$= 9.53 * 10^7$

Pr*Gr = 0.685348231*(9.53 * 10^7)

= 6.5313 * 10^7

$10^4 < (Pr.Gr) < 10^9$ therefore $Nu = 0.53(Pr.Gr)^{0.25}$

Nu = 0.53(6.5313 * 10^7)$^{\mathbf{0.25}}$
= 47.6459

Conduction

Calculation of effective thermal conductivity of dosa batter

Spherical Inclusions in a Continuous Solid Phase: (6)

Maxwell's Derivation:

$$\frac{k_{eff}}{k_0} = 1 + \frac{3\phi}{\left(\frac{k_1 + 2k_0}{k_1 - k_0}\right) - \phi}$$

k_{eff} = effective thermal conductivity

k_1 = thermal conductivity of embedded material (water) = 0.6068 $Wm^{-1}K^{-1}$

k_0 = thermal conductivity of continuous phase (rice) = 0.104 $Wm^{-1}K^{-1}$ (7)

ϕ = volume fraction of embedded material = 1/5 = 0.2

Numerator = 3 * (1/5) = 0.6
Denominator = $[(k_1 + 2k_0) / (k_1 - k_0)] - \phi$

= [(0.6068 + 2 * 0.104)/ (0.6068 – 0.104)] – 0.2

= 1.4205

k_{eff} / k_0= 1 + num/den

k_{eff}/ 0.104 = 1 + 0.6/1.4205

k_{eff} = 0.1479 $Wm^{-1}K^{-1}$ = k

Also Nu = h_cD/ k

47.6459 = [h_c * 0.2283] / 0.1479

h_c = 30.866 $Wm^{-2}K^{-1}$

Q_c = h_c(T_1- T_2)

= 30.866 (473.15 – 295.15)

= 5494.14 W

Heat transferred by conduction **: Q_h**

Q_h = kA (ΔT/Δx) (2)
= 0.1479 * 0.0166 (178 / 0.005)
= 87.40

Q_t = Q_r + Q_c +Q_h
= 36.40 + 5494.14 + 87.40
= 5617.94 W

II) percentages of respective types of heat transferred.

% **Q_r** = (36.40/5617.94) * 100 = 0.64

% **Q_c** = (5494.14 /5617.94) * 100 = 97.79

% **Q_h** = (109.25/5617.94) * 100 = 1.57

III) calculation of theoretical time

Unaccomplished change, a dimensionless ratio $\mathbf{Y} = \mathbf{(T_1 - T_c) / (T_1 - T_2)}$ (8)

Relative time $\mathbf{X = k * t/\rho * c_p * x_1^2}$

Relative position $\mathbf{n = x/x_1}$

Relative resistance $\mathbf{m} = \mathbf{k/ h_c * x_1}$

$\mathbf{T_1}$ = 473.15K

$\mathbf{T_2}$ = 295.15K

$\mathbf{T_c}$ = 195^0C = 468.15

$\mathbf{k}$ = 0.1479 $Wm^{-1}K^{-1}$
t = time

ρ = density

$\mathbf{c_p}$ = specific heat
$\mathbf{x_1}$ = 0.002m
x = distance from centre to any point

$\mathbf{h_c}$ = 30.866 $Wm^{-2}K^{-1}$

$\mathbf{Y = (T_1 - T_c) / (T_1 - T_2)}$
= (473.15 – 468.15) / (473.15 – 295.15)
= 5/178
= 0.028

$\mathbf{m = k/ h_c * x_1}$
= 0.1479/(30.866 *0.0025)
= 1.9 ≈ 2

$\rho = \rho_{eff} = (\rho_1 V_1 + \rho_2 V_2 + \rho_3 V_3) / (V_1 + V_2 + V_3)$

ρ_1 = density of rice = 753 kg/m^3 (9)
ρ_2 = density of urad dal = 760 kg/m^3
ρ_3 = density of water = 1000 kg/m^3
V_1 = 4 cups of rice
V_2 = 1 cup of urad dal
V_3 = 1.25 cups of water

$\rho = (753*4 + 760*1 + 1000*1.25)/(4 + 1 + 1.25)$
$= (3012 + 760 + 1000)/(6.25)$
$= 803.52$ kg/m^3

$$\mathbf{c_p = c_d + c_w M} \quad (10)$$

where $\mathbf{c_w}$ = 4186 J/kg K for the 0–80 °C temperature range

$\mathbf{c_p = c_d + 4186M}$

$\mathbf{c_p}$ = specific heat capacity of moist rough rice,

$\mathbf{c_d}$ = specific heat capacity of dry mass = 1109 J/kgK for unshelled rice

M = moisture content of grain =20%

$\mathbf{c_p = c_d + 4186\ M}$

$= 1109 + 4186(20/100)$

$= 1946.2$ J/kgK

Case 1) **x** = 0

n = x/x_1
= 0/0.0025
= 0

The corresponding X value for Y=0.028, n=0, m=2 is 8.1

$X = k * t/\rho * c_p * x_1^2$

$8.1 = [\ 0.1479*\mathbf{t}\ ] / [\ 803.52*1946.2*(0.0025)^2\ ]$

$8.1 = [\ 0.1479*\mathbf{t}\ ] / 9.77$

t = 532.28 s
= 8.9 minutes

Case 2) **x** = .0025

n = x/x_1
= 0.0025/0.0025
= 1
The corresponding X value for Y=0.028, n=1, m=2 is 7.5
$X = k * t/\rho * c_p * x_1^2$

$7.5 = [\ 0.1479*\mathbf{t}\ ] / [\ 803.52*1946.2*(0.0025)^2\ ]$

$7.5 = [\ 0.1479*\mathbf{t}\ ] / 9.77$

t = 495.43 s
= 8.25 minutes

Error estimation

Percentage of error = [(10-8.9)/10] * 100 = 11 (n=0)

Percentage of error = [(10-8.25)/10] * 100 = 17.5 (n=1)

Assumptions

- ✓ For the sake of simplicity, dosa is made very common. Otherwise to make it more captivating I add beetroot juice to the batter for pink dosa ,carrot juice for orange dosa etc.
- ✓ Finding the emissivity was cumbersome. I found out that generally for all food stuffs e=0.9 can be assumed.
- ✓ For effective thermal conductivity I considered water molecules as spherical inclusions in a mixture of respective amounts of rice and urad dal.
- ✓ Presuming dosa as a flat plate I calculated the time of cooking.

Comments

From the calculated percentage values we can infer that major portion of heat transferred is by convection.
In this case heat transfer by radiation is very less as it has a shape of a flat plate and is perpendicular to the walls of the oven. Otherwise it is appreciable.
Generally heat transfer by conduction in oven is less as it is immaterial of the type of material of plate used.

Acknowledgements

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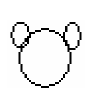
Thanks to my mother for her extensive support and invigoration.

I also owe my gratefulness to my diminutive cousins who inculcated such habits in me.

Finally heartfelt thanks to Mickey Mouse ☺



References

(1) Kenstar recipe book

(2) http://books.google.co.in/books?id=OOo98fhmEqoC&pg=RA1-PA220&lpg=RA1-PA220&dq=radiant+heat+transfer+equation+in+oven&source=web&ots=KhcI8Xy7KT&sig=u2sZf9CRiv6veJ5bDf_FCsp04gc&hl=en#PRA1-PA220,M1

(3) http://www.nzifst.org.nz/unitoperations/httrtheory5.htm

(4) http://users.wpi.edu/~ierardi/FireTools/air_prop.html

(5) http://www.engineeringtoolbox.com/air-properties-d_156.html

(6) http://www.owlnet.rice.edu/~chbe402/proj02/sleung/finalproject.htm

(7) http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6WXV-47VYJJV-5&_user=518931&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000025838&_version=1&_urlVersion=0&_userid=518931&md5=1b1f59cc13c61581b6575eaff21bee6f

(8) Fundamentals of momentum, heat and mass transfer James R Welty; Charles E Wicks; Robert E Wilson

(9) http://www.simetric.co.uk/si_kitchen.htm

(10) http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V2P-4JP9FMD-1&_user=518931&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000025838&_version=1&_urlVersion=0&_userid=518931&md5=d4c73c983c9b969809e4b6eb2af7994f

Heat transfer in food cooling applications by Ibrahim Dincer (conversions)

Engineering properties of foods by M. A. Rao, Syed S. H. Rizvi, Ashim K. Datta (basic heat transfer equations)