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P3_6 Would you like some tea?

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Abstract

This paper investigates the cooling rate of tea for two scenarios, leaving tea to sit by itself and stirring it. The calculations only factor in the heat loss from the top of the cup, neglecting heat loss via conduction through the sides. The results show that stirring the cup of tea would cool it down 0.06 times faster than leaving it to cool on its own.

Introduction

In our busy everyday lives we continuously have the problem of how to save time. The morning rush is usually the worst, and we find that the morning cup of tea is usually abandoned. This paper looks to investigate how much of an effect stirring a cup of tea would speed up its rate of cooling.

Theory

The rate at which it cools depends on the surface area of the fluid/air interface. Equation 1 is used to calculate the rate of cooling of the tea; where $\frac{dQ}{dt}$ is the rate of cooling, *A* is the surface area of the tea exposed to the air, *H* is the convective heat transfer coefficient which we take as a minimum value of $3\text{Wm}^{-2}\text{K}^{-1}$ [1] and ΔT is the change in temperature. The convective heat transfer coefficient depends on the velocity of the fluid, the geometric shape, the surface condition, viscosity of the fluid and its orientation to flow [2].

$$\frac{dQ}{dt} = HA\Delta T \qquad (1)$$

We also consider the rate of cooling a cup of tea which is being constantly stirred. To accommodate for this in equation 1 we recalculate the surface area of the tea at the top of the cup as this is where the majority of heat loss occurs. Figure 1 shows how the surface area of the tea at the top of the mug will change when it is stirred [3]. To calculate this surface area we assume that the area is the curved surface area of a spherical cap [4], given by equation 2.

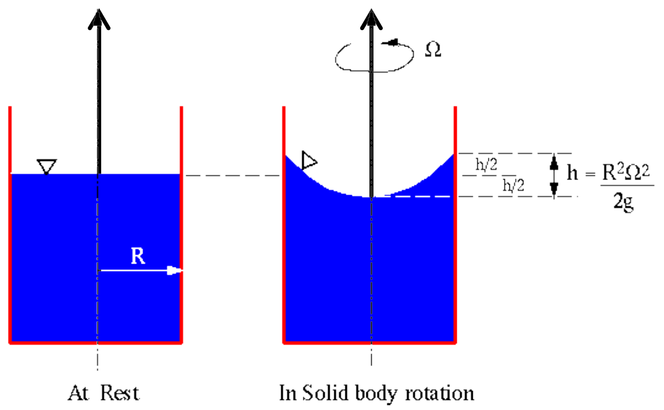

Figure 1. shows the height, *h*, at the centre of a rotating cup of water [3]

$$A = \pi(r^2 + h^2) \qquad (2)$$

In equation 2, *r* is the radius of the mug which is taken to be 4.5cm, and *h* is the height shown in Figure 1, which is the change in height of the meniscus. To work out this value of *h* we use equation 3 which takes into account the radius *r*, angular velocity *Ω* and acceleration due to gravity is *g* [3].

$$h = \frac{r^2\Omega^2}{2g} \qquad (3)$$

Equation 3 has been derived from equation 4 below, which equates the forces acting on an element in the fluid (with the mass taken as $A\rho dr$). The right hand side of the equation represents the centripetal force while the left hand side shows the force as result of pressure difference at heights h and $h + dh$. By rearranging and cancelling terms in equation 4, we obtain equation 3.

$$\rho g(h + dh)A - \rho g h A = A\rho(\omega^2 r)dr \quad (4)$$

We assume that the stirring rate is 100 rotations per minute. Therefore our value of Ω = 10 rads^{-1}. We then use this calculated value of *h* in equation 1 to find the cooling rate of the stirred tea.

Discussion

Firstly we calculate the cooling rate of the still cup of tea. The surface area at the top of the cup of tea is equal to 6.36x10^{-3}m^2, using $A = \pi r^2$. The initial temperature used is 100°C, the boiling temperature of water, and the final temperature is assumed as room temperature, 25°C, the value of *ΔT* is therefore 75°C. Using equation 1 we have calculated the cooling rate of the still tea as 1.43Ws^{-1}.

Next we do the same calculation for a cup of tea being stirred. Firstly we calculate the value of *h*, which is the height of the spherical cap using equation 3; this is equal to 0.011m. Using equation 2, the surface area is calculated as 6.74x10^{-3}m^2. Using the same temperature difference as above, the final step is to calculate the cooling rate of the stirred tea using equation 1. This is equal to a cooling rate of 1.51Ws^{-1}.

The value of *H*, the coefficient of convective heat transfer, ranges from between 3.00 to 100.00 Wm^{-2}K^{-1}. In equation 1 above we have used the minimum value of *H* to calculate the cooling rate of tea for both scenarios. However if the value used was larger (depending on its factors of density, viscosity, etc.) then the rate of the cooling would increase.

Conclusion

In conclusion we find that stirring tea increases its cooling rate and the tea cools faster by a factor of 0.06, which is a very small change in rate that would be neglected by most people. The investigations assume that the tea is continuously stirred at an average of 100 rotations per minute; which is going to be different for each individual person. Furthermore it is inaccurate to assume there will be no heating effect from the friction created between the spoon and the fluid; although this is very negligible at slower speeds it may be become a factor a higher stirring speeds.

References

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