Science Education Collection

Spin and Chill

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Overview

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The *Spin and Chill* uses the fundamentals of heat transfer and fluid flow to chill beverages to 38 F in only 2 minutes. It would take a refrigerator approximately 240 minutes and an ice chest 40 minutes to achieve the same temperature. The *Spin and Chill* also claims this is accomplished by "gently" spinning at 500 rpm, which creates little or no foaming.

In this experiment, the ability of spinning a vessel to cool a soft drink at record speeds will be evaluated. The *Spin and Chill* is designed to invalidate the use of an ice chest, in favor of chilling drinks quickly and individually. Different operational parameters, such as varying the RPM of the device, will be assessed to determine their effect on heat transfer. Additionally, both the lumped parameter analysis and transient heat conduction analysis will be used to determine heat transfer.

Principles

The *Spin and Chill* makes use of transient heat conduction and convective heat transfer. By spinning the can, warm liquid from the middle of the can moves to the outside and comes in contact with the colder surface. Then, energy is transferred from the warm liquid to the cold surface in the form of heat. This continues until the entire vessel has been cooled. Refrigeration makes use of a similar process[1]. In refrigeration, refrigerant cycles through the system, and undergoes a reduction in pressure[1]. In response, the temperature of the refrigerant severely decreases to below the temperature of the space being cooled[1]. This temperature difference results in heat moving naturally from the warmer space to the cooler refrigerant, where it is taken in, later emitted, and the process repeats itself[1].

The Spin and Chill is analogous to the cooling of a batch vessel and somewhat analogous to the cooling of a fluid flowing in a pipe. For fluid in a batch vessel with an agitator and in a pipe, the average fluid velocity is known. Theory and correlations are available to predict heat transfer coefficient (*h)* values. Heat flow in the *Spin and Chill* is controlled by resistances. We want to focus on two limiting cases.

The lumped parameter analysis reduces a thermal system to a number of discrete "lumps", where the temperature difference in each lump is considered negligible.

$$\frac{T(t)-T_\infty}{T(i)-T_\infty} = exp\left(-\frac{hA_St}{\rho C_pV}\right)$$

In this equation, T is temperature, h is heat transfer coefficient, A is area, t is run time, ρ is density, Cp is the heat capacity, and V is volume.

Heat flow from the water in the can to the ice involves an internal resistance, a wall resistance, and an external resistance (Figure 1). For case one to be applicable, both the water in the can and the ice must be well mixed. This simplifies the case to a one-dimensional heat transfer problem.

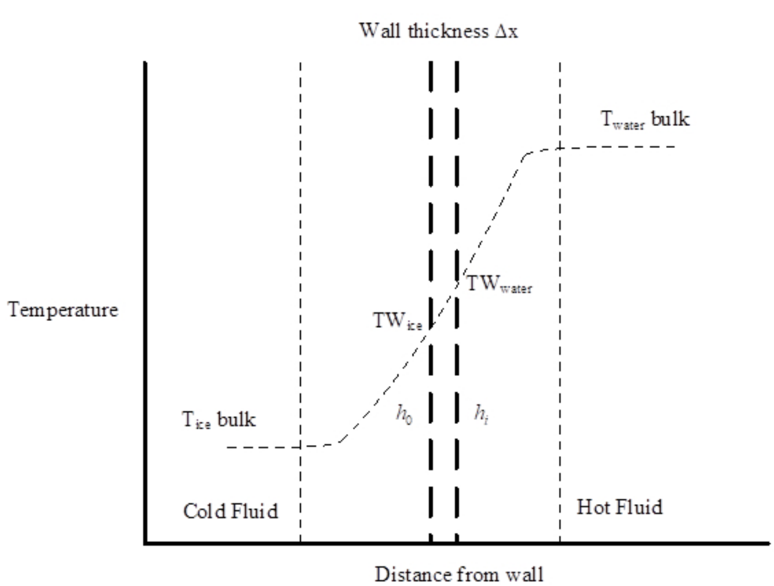

Figure 1: A schematic of temperature conditions for case one.

In this case, the wall is very thin and the wall resistance can be neglected. Here, the heat transfer is predominately controlled by the internal resistance. This leads to the lumped parameter analysis, which allows determination of the internal resistance.

The Biot number is an index of the ratio of heat transfer resistances inside and outside a membrane,

Bi = *Lh/k*

where Bi is the Biot number, L is the characteristic length (volume divided by surface area), h is the heat transfer coefficient, and k is the thermal conductivity. This number is used to compare heat transfer resistances between different bodies.

Case two utilizes a one-dimensional transient heat conduction analysis.

$$\tau = \frac{\alpha t}{r_0^2}$$

Where τ is the time constant, α is the thermal diffusivity, t is time, and r_0 is the initial radius. This formula is used to find thermal diffusivity, which consists of the thermal conductivity, k, divided by the density ρ and heat capacity, C_p.

$$\alpha = \frac{k}{\rho C_p}$$

If the water is a true "solid body", the bulk water temperature will not be uniform temperature and heat flow from the water will be controlled by conduction. With time, the temperature at the center line of the can will evolve (Figure 2). Heat flow from the water to the ice involves conduction through the "solid" and an internal resistance.

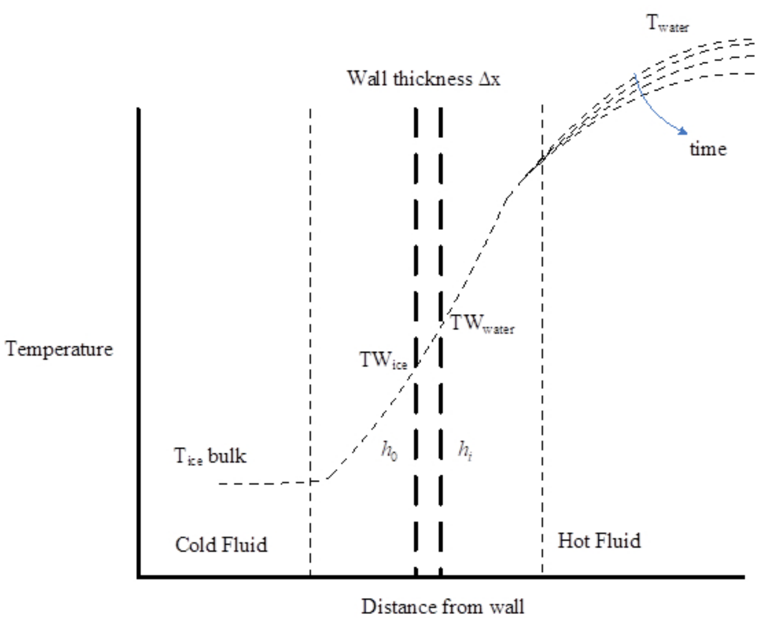

Figure 2: A schematic of temperature conditions for case two.

When using an ice chest, the liquid in the can is not as "solid" even without mixing, and natural convection will be established due to the temperature gradients. The center line temperature can be used to determine the apparent internal resistance by assuming a long cylinder with heat conduction in the radial direction.

Procedure

1. Testing the Spin and Chill

1. Fill the aluminum soda can with room temperature water and then record the temperature.
2. Measure the total weight of the ice being used with the balance, enough to surround the Spin and Chill.
3. Seal the aluminum soda can using a plastic sealing lid and insert the assembly into the *Spin and Chill.*
4. Activate the *Spin and Chill*. It should run about 2 min at ~ 500 rpm.
5. Remove the aluminum soda can from the *Spin and Chill* and remove the plastic sealing lid. Record the final temperature of the water within the aluminum soda can.
6. Record the amount of ice that melted to water using either a graduated cylinder or a balance.

2. Lumped Parameter Model

1. Starting with the can a room temperature, perform ~ 4 single runs using the *Spin and Chill* (~4). It should run for ~ 2 min at ~ 500 rpm.
2. Record the final temperature of the water within the can after each run.
3. Then, run the *Spin and Chill* sequentially three times starting with a warm can. Perform a reasonable number of replicates for the sequential *Spin and Chill* experiment. It should run for ~ 2 min at ~ 500 rpm.
4. Record the amount of ice melted and final temperature after each run. Be careful when you open the can - it may or may not foam.
5. Then, repeat and vary the operating rpm of the Spin and Chill. Start with the can at room temperature and perform 2 min runs at rpm ranging from a few to 500 rpm.

3. Transient Conduction Model

1. Perform the same experiments as above. Load the spin and chill with ice and a solid aluminum cylinder (with a small hole drilled into the center line for temperature measurements).
2. Every few minutes measure and record the temperature in the center of the can and the aluminum cylinder - be careful not to stir or disturb the can contents.

Results

The lumped parameter model is used to determine the heat transfer coefficient, h, for the different experimental conditions. The observed efficiency is not dependent on any limiting case or heat transfer mechanism. To calculate the efficiency, we first determine the energy into the ice and from the water. If the system were adiabatic (100% efficient), $Q_{water} + Q_{ice} = 0$. The efficiency is determined by dividing the absolute value of heat energy of the water (Q_{water}) by the heat energy of the ice (Q_{ice}) (Table 1). For the sequential runs, the efficiency, η, decreases from 78 % to 71 % and then to 50 % as the temperature approaches 32 F (Table 2). The efficiency, η decreases with sequential runs. This is because the efficiency of heat transfer is reduced when temperatures are close to one another. The liquid inside the can approaches the temperature of the ice outside, therefore reducing efficiency. The Biot numbers were found to be around 10 for all the single runs. These significantly exceed the expected value of 0.1. The much larger value indicates greater thermal resistance outside the can than inside. The Biot number is more accurately stated as the external resistance to heat flow divided by the internal resistance. Here, larger numbers for *h* and *k* are indicative of less resistance or "greater" heat flow. A very large *k* would create a uniform temperature in that "*k"* phase. Rotating the can appears to create a well-mixed vessel. The lumped parameter analysis is perfectly applicable.

Trial #	lbs of water	Initial Temp (°F)	Final Temp (°F)	**Δ**T (°F)	Ice **Δ**m (lbs.)	Q_{ice}	Q_{water}	**η**	h (Btu/hr-ft^2-F)	h (W/m^2-C)
1	0.783	77	53.42	23.58	0.172	24.768	18.463	74.54	70.545	400.574
2	0.783	84.74	60.08	24.66	0.17	24.48	19.309	78.88	59.899	340.126
3	0.783	86	59.72	26.28	0.175	25.2	20.577	81.66	63.369	359.829
4	0.783	83.12	55.4	27.72	0.195	28.08	21.705	77.30	74.261	421.674
6	0.783	81.86	52.34	29.52	0.212	30.528	23.114	75.71	85.207	483.832
7	0.783	83.66	58.28	25.38	0.171	24.624	19.873	80.70	64.229	364.710
8	0.783	79.16	50.72	28.44	0.203	29.232	22.269	76.18	87.804	498.576
9	0.783	81.68	56.3	25.38	0.181	26.064	19.873	76.25	67.959	385.890
10	0.783	81.86	56.66	25.2	0.173	24.912	19.732	79.21	66.905	379.906
Avg.	**0.783**	**82.12**	**55.88**	**26.24**	**0.18**	**26.43**	**20.55**	**77.73**	**70.454**	**400.057**

Table 1: Single-run nominal temperature change from 82 F to 56 F.

Trial #	lbs of water	Initial Temp (°F)	Final Temp (°F)	ΔT (°F)	Ice Δm (lbs.)	Q_{ice}	Q_{water}	h	h (Btu/hr-ft^2-F)	h (W/m^2-C)
1a	0.783	80.78	53.6	27.18	0.176	25.344	21.282	83.97	77.414	439.582
1b	0.783	53.6	41.9	11.7	0.095	13.68	9.161	67.10	74.335	422.095
1c	0.783	41.9	38.3	3.6	0.038	5.472	2.819	51.77	43.223	245.430
2a	0.783	74.48	55.76	18.72	0.137	19.728	14.658	74.30	55.216	313.530
2b	0.783	55.76	43.34	12.42	0.088	12.672	9.725	76.90	70.477	400.188
2c	0.783	43.34	37.04	6.3	0.062	8.928	4.933	55.53	77.548	440.340
3a	0.783	71.42	49.28	22.14	0.141	20.304	17.336	85.38	78.374	445.030
3b	0.783	49.28	39.56	9.72	0.077	11.088	7.611	68.78	78.767	447.264
3c	0.783	39.56	35.96	3.6	0.046	6.624	2.819	42.77	61.836	351.122

Table 2: Data from three sequential runs with nominal temperature changes.

An initial calculation of the temperature of the center using the suggested parameters suggests an impossible violation of the second law of thermodynamics. However, the problem is this equation does not provide a short time solution, only solutions over a longer term. Additional parameters must be added to satisfy shorter time periods.

$$T_{center} = (T_i - T_\infty)A_1 exp(-\lambda^2\tau) + T_\infty$$

$$T_{center} = (77 - 32)1.5677exp(-(2.1795)^2(0.01695)) + 32$$

$$T_{center} = 97.09^o F$$

Consider heat transfer resistances in the water and aluminum, *h,* and pure conduction, *k*. If the conduction is pure - as occurs in a solid body - then the observed *h* values should be the same for both systems. For the water system, some natural convection will occur, therefore the *h* values are not expected to be the same for the two systems.

When varying the rpm, it was found that the average temperature of the liquid inside the can was inversely proportional to the rpm. Higher rpms led to lower liquid temperatures, closer to the ideal temperature, whereas a reduced rpm led to higher average temperatures. Higher rpms reduced the temperature of the liquid more successfully than lower rpms.

A similar relationship was found between run time and temperature at constant rpm. When the can was spun for a reduced amount of time, the average temperature was warmer than when the can was spun for the full amount of time. The relationship was found to be that an increase in run time leads to an increased change in temperature and an overall cooler temperature on average.

Applications and Summary

This experiment is designed to assess the ability of a spinning vessel to cool a soft drink at record speeds, the *Spin and Chills*. Round one examines the *Spin and Chill* using a lumped parameter model. Round two examines the *Spin and Chill* using the transient heat conduction model in long cylinders. Round three compares our *Spin and Chill* experimental results with results and correlations found in another research experiment. Theory and correlations are available to predict *h* values. Heat flow in the *Spin and Chill* will be controlled by resistances.

The efficiency drop found in sequential runs was expected. The Biot numbers were found to be around 10 for all the runs in round one. These heavily exceed the expected value of 0.1. The data collected calls into question the ability of the *Spin and Chill* to cool at warm can of soda to 38F in 2 minutes. However, with three sequential uses and a time period of about 6 minutes, the *Spin and Chill* can cool the soft drink to the desired temperature of 38F. While the initial claims were invalidated, the concept does provide an advanced cooling method that could be made more efficient with more testing in the future.

The lumped parameter model has been applied to a wide variety of fields. By use of a lumped parameter analysis, forensics labs can determine time of death of a human body[2]. Forensic scientists treat the body as a lumped system[2]. Previous research was conducted on cooling when considering factors such as body size and shape[2]. Differential equations are then used with these known cooling factors to determine relative time of death[2].

Another use of the lumped parameter model is in the advancement of HVAC (heating, ventilation, and air conditioning) systems[3]. Heat load distribution can be computationally predicted with a lumped parameter model to maximize energy efficiency[3]. These models account for fluid transport, energy transport, thermodynamics, and psychrometrics[3]. By fitting HVAC systems to a lumped model, engineers can maximize their efficiency, reducing costs and energy usage, while increasing the effectiveness of the climate control system[3].

Transient heat conduction modeling is important in a variety of engineering fields, including materials processing, power station engineering, and refrigeration. Heat exchangers are one common application of transient heat conduction[4]. These devices take energy from a hot stream and use it to heat a cooler one[4]. Shell and tube are the most common type of exchangers[4]. They are normally long cylinders, similar to the model used for this experiment, but much larger in scale[4]. Several tubes inside a larger cylinder shell contain one flowing liquid, while a separate one flows through the shell[4]. Flow can be in the same or different directions. Heat will flow from the hottest stream to the colder one[4]. These tools can be used in many industries, such as chemical manufacturing and oil refining, where they can be used to heat or cool chemicals or oil[4].

References

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