

A theoretical hypothesis of beverage cooling by reverse heating in consumer microwave ovens by using fullereneol (polyhydroxylated fullerenes) dissolved in acetone

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Abstract: Cooling of beverages is of large interest. Here a theoretical idea of how microwave ovens can be used for cooling beverages is presented. The proposed theoretical idea based on heat transfer features a microwave safe (isoprene rubber) torus shaped rubber ring (*MWSR*) holding a liquid (*L*) at room temperature. Fullereneol dissolved in acetone (*L*) inside *MWSR* (*L*) will absorb energy directly from the microwave radiation and thereby increase its temperature. The liquid to be cooled (*B*) will also absorb energy from the microwave radiation, but the net effect is the cooling of *B* as the heat transfer is faster in *L* than in *B* due to *L*'s lower boiling point and heat of vaporization. The cooling fan of the microwave oven facilitates the heat transfer mechanism. The beverage *B* is theoretically cooled from room temperature (20 °C) to around 4 °C in around 58 seconds. Based on heat absorption of fullereneol—which could be transformed from liquid phase to vapour phase—a beverage liquid (300 g water) in a glass put inside the microwave oven could be cooled (reversely heated) by the heat generated by the microwave oven. The user of the proposed method would be able cool 300 ml of beverage to less than 4 °C in just a minute using consumer microwave ovens.

Key-Words: Cooling; microwave radiation; fullereneol, acetone; isoprene rubber

1 Introduction

Cooling of beverages is of interest. Thermoelectric coolers or Peltier coolers have been used to pump heat in the opposite direction of the natural heat flux [1]. Peltier technology was applied to design and fabricate a portable thermoelectric beverage cooler and thermoelectric cup [2].

Quick cooling of beverages is rather well covered by patents [3]–[12]. The important performance metrics to consider are the cooling speed and extra incurred cost to the end-user.

The following briefly describes other methods for quick cooling of beverages. The methods are

categorized as less complicated machines, more complicated machines, refrigerator solutions and fluid dynamic solutions.

1.1 Less complicated machines

Hempell proposed a device filled with ice and water providing quick cooling of beer kegs and other beverage containers [3]. Hu proposed a quick cooling cup consisting of an inner cup and an outer cup [4]. Neither Hempell nor Hu provided any quantification of cooling time and cost compared to the state-of-the-art.

1.2 More complicated machines

Loibl et al. [5] proposed to use one or more beverage containers to be rapidly rotated along their

respective longitudinal axes while being downwardly vertically sprayed with a cooling water spray, with the water being in a 0 °C temperature equilibrium with ice, thereby cooling the cans from room temperature to a drinking temperature of 5 °C *in under one minute*.

Zhang [6] suggested a utility model for quick cooling comprising a refrigerating unit, an evaporator, a corrosion prevention pump and a refrigerator. No quantifications of cooling time and cost were given.

Lin [7] proposed a quick cooling device for beer and beverage in small package, which comprises a refrigerating unit, a cooling tank and an electric control portion. No quantifications of cooling time and cost were given.

Sundhar [8] proposed a quick cooling device comprising a compartment with a door allowing access to a quick cooling chamber. No quantifications of cooling time and cost were given.

Chen [9] proposed a beverage liquid quick cooling machine including a cooling circulatory system and a heat exchanging circulatory system. No quantifications of cooling time and cost were given.

1.3 Refrigerator solutions

Yang [10] invented an auxiliary device arranged in a refrigerator as a quick cooling beverage device.

Lin [11] proposed a cooling device with a large contact area, thereby achieving a relatively high beverage cooling speed. However, neither Yang [10] nor Lin [11] provided any quantifications of the time it will take to cool liquids with their inventions.

1.4 Fluid dynamic solutions

Vartan [12] proposed the V-tex machine which uses water to carry the heat from the beverage being cooled. Uniform cooling is reached by creation and destruction of a “Rankine vortex”. The claim is that a 500 ml glass bottle can be cooled in six minutes and a metal can in about 50 seconds. An 80% electricity usage saving compared to conventional machines is claimed [12].

1.5 Summary of others solutions

As described above, there is a growing interest of cooling beverages faster than the speed provided by a refrigerator. Loib et al. [5] and Vartan [12] wrote the patents representing the “cutting edge” cooling of contained beverages, whereas the present theoretical idea considers beverages poured into a glass (cylinder).

In households however — without buying a

new machine — there are few ways of quickly (seconds) cool a glass of water or a jug of lemonade. The proposed theoretical idea is not introducing a new machine or apparatus, thereby potentially avoiding energy use of manufacturing and excessive waste.

The proposed theoretical idea will use already existing technologies to achieve the cooling effect, although a phase transition medium has to be used in conjunction to the microwave oven that absorbs the excess heat.

No publication could be found describing how consumer based microwave ovens are used for reverse heating (cooling) of beverages contained in glasses or jugs (pitchers), let alone using fullerenols dissolved in acetone.

1.6 Gaps in existing literature

There is no open method which describes how to cool beverages in glasses or jugs in seconds using microwave ovens. There are no technical problems to be solved in prior art with the introduction of this theoretical idea. Speed of cooling for individual use is the only limitation with prior methods, except from [12], which is used for cooling beverages. The research herein addresses a new way of cooling beverages poured into glasses in a competitively fast way.

Microwave ovens have not been used before for cooling beverages. This solution would avoid the manufacturing of special cooling machines.

2 Problem Formulation

In the present research the hypothesis is that the speed of cooling is similar to (or better than) existing methods for cooling beverages poured into glasses.

3 Problem Solution

In this report we suggest a hypothesis about consumer based microwave ovens to be used for cooling beverages poured into glasses by reverse heating.

The proposed theoretical idea features:

- a microwave safe (isoprene rubber) torus shaped rubber ring (MWSR).
- a liquid (L) inside $MWSR$.
- L should have a relatively low boiling point (around 40°C) compared to the liquid to be cooled (B , which is a beverage close to water or lemonade),

otherwise both L and B will be heated simultaneously. L should also have appropriate molar mass (M_L), heat of evaporation (dH_L), and heat capacity ($C_{p,L}$).

- Water-soluble fullerenes are promising materials for use in the field of life science and as medicines or cosmetic ingredients [13].
- Fullerenol (Figure 1) dissolved in acetone is identified as suitable L .

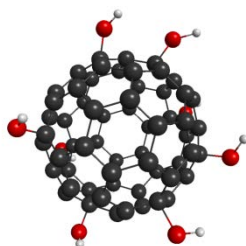


Fig.1 Fullerenol molecule made with Macmolplt [14]

- L will absorb energy directly from the microwave radiation and thereby increase its temperature.
- B will also absorb energy from the microwave radiation, but the net effect is cooling of B as the heat transfer is faster in L than in B due to L 's lower boiling point ($T_{b,L}$) and heat of vaporization.

The cooling fan of the microwave oven facilitates the heat transfer mechanism as outlined above. Note that the rate of evaporation and condensation of the liquid L is different below and above the phase transition point, as in most common processes.

First the completely sealed isoprene rubber torus ($MWSR$) containing the fullerenol (L) is attached around the glass containing the beverage. This is done outside the microwave oven. Then the microwave oven door is opened and the glass and $MWSR$ is inserted. Then the timer is set for 58 seconds (explained in clause 2.1) for full heating. Then the microwave oven is started. After 58 seconds $MWSR$ (with L) and the glass is taken out and $MWSR$ is removed. The temperature of B inside the glass will then be around 4 °C.

The idea is to use ordinary 20×20×20 cm³ microwave ovens (with around 0.8kW microwave power capacity) used in most homes globally to cool 0.3 liter of beverage (B), such as water, poured into a glass. More amount of B would in turn require more amount of fullerenol (L) and the cooling would take longer time.

Fig. 2 shows schematically how the beverage in the glass (B) and $MWSR$ – containing the liquid which evaporates – interact.

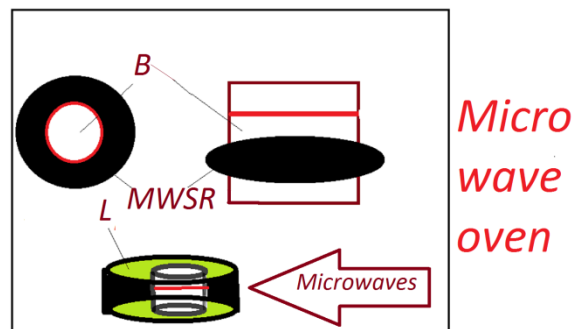


Fig.2 Sketch showing the beverage (B) in the glass and microwave safe rubber torus ($MWSR$) with evaporating liquid (L) and how they interact.

3.1 Heat transfer mechanism and calculation of cooling time

Here follows the calculation of the time it would take to cool m_B [0.3 kg (300 ml) water] (poured into a glass) put into a microwave oven.

Table 1 shows various properties of water (B) and fullerenol in acetone (L).

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Table 1. Various properties used for the calculations.

Property	Water (B), H ₂ O	Reference	Acetone – fullerenol (L), fullerenol (single) immersed in acetone, C ₆₀ (OH) ₇	Reference
C_p	4.183	kJ/[kg×K] [15]	0.809	162.313 calories/[mol×K] × 4.183 = 678 J/(mol×K), 678/839 [g/mol] = 0.809 J/[g×K] = 0.809 kJ/[kg×K]. 162.313 calories/[mol×K] is obtained via commercial computational chemistry software.
M	18	g/mole	839	g/mole
dH	2257	kJ/kg	1557	Internal energy 312.329 [kcal/mol] = {1kcal=4.183kJ} [312.29×4.183/[0.839]]
				= 1557 kJ/kg. 312.329 kcal/mol is obtained through commercial computational chemistry software.
T_b	100		≈45 °C, ≈318 K	The boiling point is estimated.
			Fullerenol+acetone	
T_m			≈-50 °C	The melting point is obtained from Fig. 5. in [16].
h	15	cm		The typical height of the glass containing B.
r_c	5	cm		The typical radius of the glass containing B.
A_c	471 of 628	cm ² See Eq.7		$2 \pi \times r_c \times h$ is the heat transfer area
r	4.5	cm		Typical inner radius for MWSR
R	11	cm		Typical outer radius for MWSR
S_{MWSR}	994	cm ² See Eq.8		Area of MWSR
V_{MWSR}	1615	Cm ³ See Eq. 1		Volume of MWSR

3.1.1 Volume limitation inside the microwave oven

The volume of a typical microwave oven (V_m) used in homes is around $20 \times 20 \times 20 \text{ cm}^3 = 8000 \text{ cm}^3$. As a consequence L can only be allowed to expand from its liquid state to less than 8000 cm^3 in gaseous state. According to Eq.1 the volume of $MWSR$ (V_{MWSR}) is estimated to 1615 cm^3 .

$$V_{MWSR} = \frac{1}{4} \pi^2 \times (R+r) \times (R-r)^2$$

(1)

$$V_{MWSR} = \frac{1}{4} \pi^2 \times (11+4.5) \times (11-4.5)^2 = 1615 \text{ cm}^3$$

3.1.2 Estimation of volume of gas of L created

The volume of ideal gases – in this case the evaporated L – can be estimated with Eq. 2 based on the amount (moles, n) the pressure p and the temperature T :

$$V_L = n \times R \times \frac{T_b}{p} \quad (2)$$

$$V_L = 0.035 \times 82.057 \times \frac{318}{1} \approx 913 \text{ cm}^3$$

0.035 moles of L (n_L), $T=45^\circ\text{C}$ and $p=1$ atmosphere are found to generate $\approx 913 \text{ cm}^3$ of L , i.e. below the volume of the microwave oven (V_m) 8000 cm^3 , and the volume of the rubber ring (V_{MWSR}) 1615 cm^3 , respectively.

3.1.3 Calculation of time to cool 300 ml B

The starting temperature inside the microwave oven and of L and B ($T_{i,MWL,B}$) is assumed to be 20°C .

The target is to raise the temperature of L to its boiling point 45°C .

We believe that the simulation and physical model presented by Eqs. 3-13 illustrate a proper heat transfer mechanism.

It is assumed that the radiation energy is distributed equally within the microwave oven implying that L and B get the same input of energy. The initial temperature increase of B – dT_1 – is estimated by Eq.3:

$$dT_1 = \left[[T_{b,L} - T_{i,MWL,B}] \times C_{p,L} \times n_L \times \frac{\frac{M_L}{1000}}{m_B \times C_{p,B}} \right] \quad (3)$$

$$dT_1 = \left[[45 - 20] \times 0.809 \times 0.035 \times \frac{\frac{839}{1000}}{0.3 \times 4.183} \right] = 0.474^\circ\text{C}$$

The temperature of B (T_B) before the phase change of L is estimated by Eq.4:

$$T_B = T_{i,MWL,B} + dT_1 \quad (4)$$

$$T_B = 20 + 0.474 = 20.474^\circ\text{C}$$

For a first order phase change of an amount of L to happen immediately, heat energy dH_L is required. The dH_L necessary to vaporize $0.035 \text{ mol } L$ ($\{m_L=29.36 \text{ grams } L\}$) is estimated according to Eq.5:

$$dH_L = n_L \times \frac{M_L}{1000} \times dH \quad (5)$$

$$dH_L = 0.035 \times \frac{839}{1000} \times 1557 = 45.72 \text{ kJ}$$

The only sources from which energy can be transferred are from the surrounding air, the microwave oven and B . B is cooled by heat transfer proportional to the area (A). As a ring torus surrounds a cylinder, the heat transfer area A is around 47% of the total area S_{MWSR} according to Eqs.6-8:

$$A = \frac{A_c}{S_{MWSR}} \quad (6)$$

$$A_c = 2\pi \times r_c^2 + 2\pi \times r_c \times h \quad (7)$$

$$A_c = 2\pi \times 5^2 + 2\pi \times 5 \times 15 = 628 \text{ cm}^2$$

Note however that only the second product, $2\pi \times 5 \times 15$ giving the outer area 471 cm^2 , is the heat transfer area of interest.

$$S_{MWSR} = \pi^2 \times (R^2 - r^2) \quad (8)$$

$$S_{MWSR} = \pi^2 \times (11^2 - 4.5^2) = 994 \text{ cm}^2$$

$$A = \frac{471}{994} \approx 0.474$$

where

$A_c = 471 \text{ cm}^3$ [Outer area of cylinder containing B]
 $S_{MWSR} = 994 \text{ cm}^3$ [Total area of ring torus exposed to microwave radiation]

The heat energy transfer possible according to A is given by Eq.9:

$$H_A = A \times dH_L \quad (9)$$

$$H_A = 0.474 \times 47.72 = 21.66 \text{ kJ}$$

The temperature decrease of B (dT_2) after evaporation of 0.035 mole of L is given by Eq.10:

$$dT_2 = \frac{H_A}{[m_B \times C_{p,B}]} \quad (10)$$

$$dT_2 = \frac{21.66}{[0.3 \times 4.183]} = 17.26 \text{ }^\circ\text{C}$$

The final temperature of B ($T_{B,final}$) after the phase change of L is estimated by Eq.11:

$$T_{B,final} = T_B - dT_2 \quad (11)$$

$$T_{B,final} = 20.474 - 17.26 = 3.21 \text{ }^\circ\text{C}$$

We argue that it is possible to remove the $MWSR$ from the glass before too much condensation has occurred. The reason is that the vaporized liquid of L has a lower heat conduction coefficient compared to the liquid L .

The energy E needed to cool m_B (0.3 kg water) is given by Eq.12:

$$E = \left[[T_{b,L} - T_{i,MW,L,B}] \times \frac{M_L}{1000} + dH \right] \times \frac{m_L}{1000}$$

$$(12)$$

$$E = \left[[45 - 20] \times \frac{839}{1000} + 1557 \right] \times \frac{29.36}{1000} = 46.32 \text{ kJ}$$

The time t to cool 0.3 kg water using the proposed theoretical idea is given by the microwave power of the microwave oven, P {assumed 0.8 kW} and E according to Eq.13:

$$t = \frac{E}{P}$$

$$(13)$$

$$t = \frac{46.32}{0.8} \approx 57.9 \text{ s}$$

4 Results

The beverage B is theoretically cooled from room temperature (20 °C) to around 4 °C in around 58 seconds. At the same time, the torus area returns to its original state allowing the system to be ready for a new cooling run. It is plausible that vaporization is faster than the condensation and that it is possible to remove the $MWSR$ before too much condensation has occurred. Nevertheless, the time for the system to return to its original state is not calculated, however, estimates depend strongly on the quality of the rubber for $MWSR$ — which requires a high content of the petroleic components— or alternatively, use natural rubbers composed of polymers of isoprene.

5 Discussion

The theoretical idea saves time and space when individuals want to cool 300 ml of beverage poured into a glass.

While the energy property changes reflect a decrease in temperature of the beverage (B) in the glass, it would require heat to flow from a temperature of 4 °C to 20.474 °C, from cold to hot. We argue, however, that – in the present system - it is not a violation of the second law of thermodynamics as the rate of the transition is dependent on the

temperature and the volume to area ratio among other things.

At the start of the process the main heat transfer mechanism will be heat conduction and heating by the microwaves. However, beyond — or for a temperature above the transition point — conduction will be less effective and heat transfer will be dominated by convection — i.e. by movements in the vaporized liquid. In the vaporized liquid of L , the heat conduction coefficient is decreased compared to the liquid of L . From these arguments it is plausible that vaporization of L is faster than the condensation of L and that it is possible to remove the MWSR before too much condensation of L has occurred. Thus the water (B) can have a final temperature that is lower than the starting temperature. The MWSR will then equilibrate with the surrounding environment. Here is presented a theoretical model which includes a heat transfer mechanism between the cooled beverage and the MWSR.

There are several alternative solutions for cooling liquids poured in glasses/jugs. These are e.g. refrigeration, freezing and some of the previously described patents [3]-[12]. All except [12] likely have slower cooling time than the proposed theoretical idea which target individuals who want to quickly cool “warm” beverages [≈ 300 ml] just poured into glasses, and those not wanting “one more machine in the kitchen”.

Would the present solution avoid some use of primary energy, compared to competing solutions? A comparative life cycle assessment [17]—with a comparable functional output such as “300 ml volume of B cooled from 20 to 4 °C”—would shed more light on this energy tradeoff issue. Nevertheless, it might take hundreds of MJ to manufacture one V—tex cooler. On the other hand it could take thousands of MJ/kg [18] to produce fullerenols, but likely only tens of MJ/kg to produce isoprene rubbers. This means that the life cycle energy balance for the present system is much dependent of how the fullerenols are produced and how much volume can be cooled with MWSR’s compared to e.g. the performance of the V—tex.

As alternative to fullerenol, di-fullerenol (Fig. 3) can be used, having two cross-linked fullerene cages. Their linked state may increase the thermal capacity (C_p).

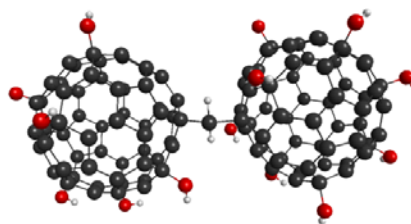


Fig.3 di—Fullerenol molecule made with Macmolplt [14].

The present theoretical idea is to use consumer microwave ovens to cool beverages by reversed heating (diffusion) by vaporization of fullerenol inside an isoprene rubber torus. There will be a direct microscopic exchange of kinetic energy of particles through the boundary between L inside MWSR and B .

6 Conclusion

Based on heat absorption of fullerenol—which could be transformed from liquid phase to vapour phase—a beverage liquid (300 g water) in a glass put inside the microwave oven could be cooled (reversely heated) by the heat generated by the microwave oven. The user of the proposed method would be able cool 300 ml of beverage to less than 4 °C in just a minute using consumer microwave ovens.

7 Next steps

An issue with the present idea is that the material of MWSR is underspecified and that the experimental investigation is lacking. The uniformity of the cooling is therefore not verified. The life cycle energy efficiency compared to e.g. the V—tex could be explored.

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