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Calculating the optimum temperature for serving hot beverages

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ABSTRACT

Hot beverages such as tea, hot chocolate, and coffee are frequently served at temperatures between 160 °F (71.1 °C) and 185 °F (85 °C). Brief exposures to liquids in this temperature range can cause significant scald burns. However, hot beverages must be served at a temperature that is high enough to provide a satisfactory sensation to the consumer. This paper presents an analysis to quantify hot beverage temperatures that balance limiting the potential scald burn hazard and maintaining an acceptable perception of adequate product warmth. A figure of merit that can be optimized is defined that quantifies and combines both the above effects as a function of the beverage temperature.

An established mathematical model for simulating burns as a function of applied surface temperature and time of exposure is used to quantify the extent of thermal injury. Recent data from the literature defines the consumer preferred drinking temperature of coffee. A metric accommodates the thermal effects of both scald hazard and product taste to identify an optimal recommended serving temperature.

The burn model shows the standard exponential dependence of injury level on temperature. The preferred drinking temperature of coffee is specified in the literature as 140 ± 15 °F (60 ± 8.3 °C) for a population of 300 subjects. A linear (with respect to temperature) figure of merit merged the two effects to identify an optimal drinking temperature of approximately 136 °F (57.8 °C).

The analysis points to a reduction in the presently recommended serving temperature of coffee to achieve the combined result of reducing the scald burn hazard and improving customer satisfaction.

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1. Introduction

The high temperature range typically recommended for serving hot beverages commercially (recommended to be on the order of 185 °F (85 °C)) presents a substantial scald burn hazard to consumers [1], and many such injuries occur annually [2,3]. A reduction in the number and severity of these injuries has been a long-standing objective within the burn prevention community. One step toward that goal is to construct an analysis tool that can be used to predict the quantitative effect of altering the beverage temperature on changing the potential for scald injury.

The propensity for hot liquids to produce burn injuries to skin has been measured and modeled for more than a half

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century [4,5]. These analysis tools were accepted and applied very widely within the biomedical engineering and science community. Based on experimental and computationally derived data, it is very straightforward to predict the benefit in reduced injury potential that would be gained by lowering the service temperature of hot beverages. The incremental benefit is largest at the highest temperatures owing to the exponential dependence of the rate of injury on the absolute temperature. The obvious conclusion is that the lower the serving temperature, the less is the potential for causing a burn in the case of a spill accident.

However, it is not possible to reduce the temperature of a hot beverage without limit because at some point consumers will discern that their hot beverage is not warm enough to satisfy their expectations. It should be anticipated that for a population of users a spectrum of preferred drinking temperatures would be identified, with some being hotter and some colder than the average value. If a threshold temperature range for satisfaction can be identified, then higher values would have the combined effects of increasing burn hazard and decreasing consumer satisfaction, both of which are undesirable. At sub-threshold temperatures, injury potential would continue to be reduced, as desired, but consumer satisfaction would be compromised. Identifying the incremental contributions of a change in beverage temperature (as a function of the absolute value of temperature) to altering the scald hazard and the product quality is one of the primary challenges addressed in this study.

Coffee is an extremely popular beverage. Nearly 8 of 10 Americans drink coffee, consuming more than 300 million cups per day, many of which are served commercially. The National Coffee Association of U.S.A., Inc., recommends that the temperature of a coffee must be maintained between 180 °F and 185 °F (82.2 °C and 85 °C) for optimal taste [6,7]. This recommendation has carried considerable influence in establishing the policies for serving temperatures for many commercial vendors.

In contrast to this recommended serving temperature, data has been published recently that identifies an average of approximately 140 °F (60 °C) as the temperature at which consumers prefer to drink coffee [8]. A group of 300 subjects were enabled to adjust their coffee temperature by adding condiments and dilution with cooler beverage to achieve drinking conditions they considered most favorable. For this study group the standard deviation in drinking temperature was about $\pm$15 °F (8.3 °C). The preferred drinking temperature is considerably lower than is traditionally recommended for serving coffee, and such a reduction would have a major impact on lowering the number and severity of scald burns caused by hot beverage spills.

The challenge addressed in this study is to identify an algorithm for combining the quantitative thermal effects of reducing scald burn hazard while maintaining consumer perceived product quality. Quantitative measures of how temperature influences both of these phenomena are developed individually and then combined into a single metric for optimization of serving temperature.

The hypothesis of this study is that a tradeoff can be defined in specifying hot beverage serving temperatures whereby a compromise is achieved in reducing scald burn hazard while maintaining acceptable product quality.

2. Scald burn model

This paper addresses the issue of how the current serving standards for coffee could be adjusted based on consumer taste preference to provide a level of protection to individuals from scald burns. The analysis approach adopted is to simulate the injury process using an Arrhenius-kinetics based mathematical model for molecular damage, as postulated more than a half century ago by Henriques and Moritz [4,5] and Büttner [9,10], to describe and predict thermal insult effects in skin. The kinetics approach to modeling burn injury has been adopted by a large number of researchers over the intervening years, and its veracity has been well documented. The methods and results of prior work on modeling thermal injury have been reviewed periodically in the biomedical engineering literature [11–14] and are well accepted. The current study applies this well-accepted approach to modeling thermal injury in combination with recent data on the customer preferred temperatures for drinking hot coffee to develop a new quantitative metric for defining a serving temperature that accommodates considerations of both scald safety and customer perceived product quality.

The modeling process is implemented in two steps. First, the transient expression of the temperature field within the affected tissue is calculated as a function of the system constitutive properties and geometry, plus the thermal conditions imposed on the surface. Next, the temperature data is applied in an injury kinetics algorithm to calculate the extent of accrued damage.

The phenomenalogical model applied in the present study is based on the analysis of human skin as a system, which requires identifying the pertinent features and properties. In many scald burns the lateral extent of the burned area is measured on a length scale of centimeters, whereas the depth of the thermally affected tissues is more than an order of magnitude thinner. This small depth/breadth aspect ratio justifies the assumption that from a local perspective spatial gradients in the temperature field are greatest normal to the skin surface. Further, the thickness of the skin is very small in comparison with the radius of curvature of the skin surface over nearly all sites on the body. These aggregate assumptions lead to the addressing of the heat transfer and burn processes as varying along a single Cartesian coordinate into the skin, which reduces to the problem of one dimensional transient phenomena in a semi-infinite medium, as illustrated in Fig. 1.

When a hot beverage is spilled onto the surface of the skin heat is transferred via convection to the tissue, from which it diffuses inwardly. The convective process consists of a combination of diffusion along a temperature gradient and advection due to bulk motion of the liquid. The diffusive component of convection will always be present, but the role of advection may vary widely depending on factors such as the amount of liquid spilled the type of clothing covering the affected area of skin. The thickness of the body is such that the diffusing heat will penetrate continually deeper without encountering another exterior surface. This arrangement is known as a semi-infinite medium, and the boundary conditions and properties are described collectively in terms of the information given in Fig. 1.

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