International Journal of Engineering and Applied Physics (IJEAP)
Vol. 3, No. 1, January 2023, pp. 673~677
ISSN: 2737-8071

Exploring the physics principles in cooking

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Article Info

Article history:

Received Aug 23, 2022
Revised Sep 02, 2022
Accepted Oct 29, 2022

Keywords:

Cooking
Phase transformation
Thermal conductivity
Specific heat
Thermal Diffusivity

ABSTRACT

A kitchen can be considered as a physics lab in which several concepts of heat and thermodynamics and mechanics can be visualized. The process of cooking can involve several phase transformations. Different terminologies used in cooking like steaming, frying, broiling, grilling can be related to rate of heat transfer. The taste of food can be considered as an output of time temperature transformation being cooked. The product of time, temperature and nature of medium used for cooking can decide the quality of food. Understanding the concept of thermal conductivity, specific heat and thermal diffusivity can lead to optimized time of cooking. Cooking can be used to demonstrate the law of conservation of angular momentum by spinning a raw egg and a boiled egg.

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1. INTRODUCTION

Cooking is a process of utilizing the heat to prepare food which becomes edible. It involves physical and chemical changes which makes food tasty and also reduces the risk of illness carried with raw food. It can be considered as a unique human activity where there is lots of intellect involved. The taste of the food can be decided by the amount, quality of ingredients, Temperature, Time, Medium and nature of material used for cooking. In recent years the source of heat transfer has also decided the taste of cooking. The various sources available include LPG, Induction stove, Electrical heaters, Microwave ovens and solar cooking. Irrespective of the sources of heat, heat transfer is a crucial process which decides the amount of food being cooked in a given time. Heat transfer can take place through conduction, convection or radiation or a combination of the processes to cook the food. The rate of heat transfer can lead to various types of cooking processes like steaming, grilling, frying and broiling. The application of heat to the raw ingredients can lead to phase transformations which make the cooked food. The phase transformations are noticed macroscopically by a change in color, smell and reduction in volume. The basic physics principles behind cooking can be phase transformations, Thermal conductivity, specific heat and thermal diffusivity.

Phase Transformations in Cooking

The phase can be considered as a physically separable portion of matter or a region of matter where unique properties exist. Generally, six phase transformations are observed for the solid, liquid and gas phases which include Melting, Vaporization, Deposition, and Sublimation Condensation & Freezing. Cooking can be considered as a process of multiple phase transformations. The phase transformations can be appreciated in boiling milk, steaming of idlies (savoury rice cake), boiling of eggs, toasting of Indian bread (Roti), grilling of chicken, transformation from butter to ghee, etc.

The preparation of ice cream involves a phase change from liquid to solid (Freezing). Making ghee from butter involves melting. Boiling of water in a closed vessel is used to cover the new batter to rice cakes (Vaporisation). Sublimation is an important phase change for freeze-drying in the food industry. Condensation can be used to purify water Deposition can observed in windowpanes on a kitchen when moist air comes in contact with a freezing cold window pane.

Usually, a solid phase transforms into a liquid on application of heat. The solid and the liquid coexist from start to the finish of phase transformation. Phase transformations observed with metals are reversible in nature. The phase transformations involved in cooking processes are irreversible. The preparation of idlies by the process of steaming is a unique phase transformation where the liquid phase of batter evaporates, and the solid phase of batter is transformed to a condensed matter of a defined shape. The boiling of eggs has been investigated in depth and it can be considered as a process of unfolding the proteins. It has been reported that with an increase in time of boiling, the yolk of the egg solidifies and the albumen formation proceeds. This is similar to a time temperature transformation (TTT) observed with steel or other alloys. The transformations taken place in cooking food can also lead to a change of taste.

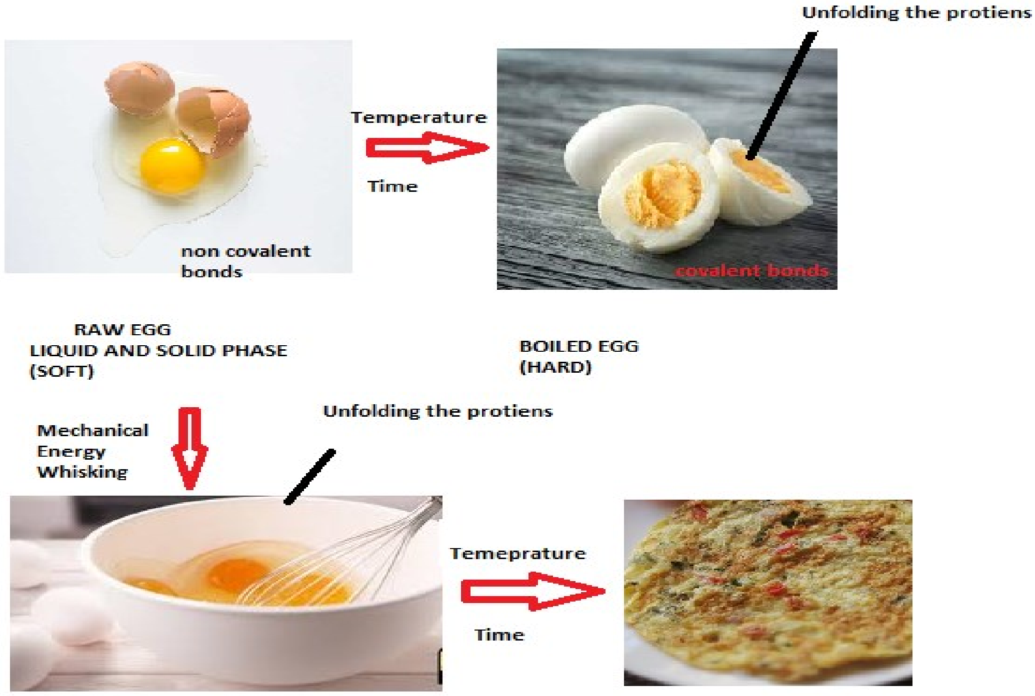

Figure 1. Phase Transformations in Egg

The boiling of eggs brings physics and chemical change. The eggs become hard due to the unfolding of proteins and evaporation of water molecules surrounding each protein molecules. In the raw egg, the proteins are held in place by weak noncovalent bonds. When heat is supplied to the eggs, the proteins gain more energy to form new stronger covalent bonds. Heat can completely unfold or denature the proteins in the egg to make them hard. Thus, the driving cause for the phase transformation in the egg is due to heat. The optimum time for boiling of egg is around 13 minutes when the temperature is close to 65C as reported by D, Buay and coworkers [1]. Boiling an egg can take more time in the mountains due to reduced atmospheric pressure. Further details on boiling and the equations governing the heat transfer can be found in A Boonkird [2].

The phase transformation in the albumen (egg white) can also be brought about by addition of chemicals like voltka or vinegar which can break the weak hydrogen bonds or ionic bonds and make the albumen harder. But this chemically induced phase transformation does not work on the yolk which is rich protein but has a greater fat content. Yet another way of inducing the phase transformation is in the process of whisking where mechanical energy is supplied. The mechanical stirring causes the protein molecules to break and reconnect. During this process the yolk and the egg white are mixed to produce a single phase. The phase can be spread on a hot pan to yield a different taste (omlet). Several phase of steel like Austenite, Martensite, Bianite, Tempered martensite can be obtained by controlling the heat treatment temperature and cooling rate. An analogous product variation can also be observed with eggs as an example. In kitchen Time temperature transformations in alloys proceeds with a change in microstructure. Similarly, the time temperature transformation proceeds in cooking of an egg with the unfolding of proteins and taste.

Thermodynamic properties are crucial in understanding and controlling the phase transition taking place in food during cooking.The texture of food can also be controlled by phase transitions.The phase change of ice crystallization is considered as the equilibrium states in food freezing [3].Asih dahil and coworkers have discussed the multiphase and multi transport phenomenon taking place during the cooking of meat.Frozen meat is depicted as a porous solid with water,fat ,protein and ait trapped in its pores and cooking meat is a process of water and fat getting transported to the pores.[4]

Phase changes involve more of energy consumption .Heating 100g of water from 30C to 100C requires 7000cal whereas boiling 100g of water requires 54000 calories .The energy consumption is almost greater by a factor of 7.7.The increasing demand for energy consumption is a global threat.Further this also involves greater carbon dioxide emission.Recently phase changes in cooking are also achieved through solar cookers which offer several advantages.Solar cookers utilize a renewable source of energy and no fuel cost.The disadvantage of solar cookers on a rainy day can be overcome with thermal storage mechanisms.Phase change materials drive the thermal storage materials and improve the efficiency of solar cookers.[5]Insulated solar energy cooking ,has been proposed as a modern technology for cooking.[5] Insulated solar energy cookers consist of a solar panel ,electric heater and an insulator material.The most commonly used insulating material are rice hull,straw,polyurethane chips and fiber glass.[6] .Thus phase changes are observed during cooking and are also a means of enhancing the solar cookers efficiency using phase change material concept. Entropy changes are also accompanied by phase transitions. Entropy is understood as a degree of randomness and can also be considered as the ratio of heat absorbed or rejected by the temperature. Dissolving salt in water, making pop corn, boiling water or milk are all associated with phase change and entropy changes. Majority of the phase changes in food are phase changes that occur in components of food-carbohydrate,proteins,lipids and water.[7]

Thermal Conductivity

Thermal conductivity of the material can be understood as the ability of the material to transfer heat in presence of a thermal gradient. Cooking is a process of making food through application of heat where a heat transfer element and heat transfer medium is required. Thermal conductivity of the heat transfer medium can decide the time of cooking and also alter the taste of the food. A higher thermal conductivity medium can cook the desired food in a lesser time. Cooking utensils can be made from Copper, Steel, Aluminium or Earthen pots. These utensils have different thermal conductivity. In addition to thermal conductivity the heat capacity also affects the rise in temperature of the material. A material with high capacity will take more time for the temperature to rise. Hence material with low heat capacity is to be preferred for the quick heat transfer. Thermal conductivity and heat capacity can be the two deciding parameters for required heat transfer. The ratio of thermal conductivity to heat capacity can be a single parameter which determines how much heat will be transferred to the material and spread out within the material. The ratio is called as thermal diffusivity and is high for Copper, Aluminum or earthen clay pots in comparison to steel.

Table1. Thermal conductivity and Thermal diffusivity of cooking utensils

Material	Thermal conductivity W/m-K	Thermal diffusivity (10^{-6}) m^2/s
Copper	401	120
Aluminum	237	100
Cast iron	80	22
Stainless steel	16	4.3
Earthen clay pot	1.002	106

In addition to thermal conductivity of the utensil used, the thermal conductivity of the medium used for cooking can also change the rate of heat transfer and taste of the food. For boiling or steaming water is used as the medium and for frying various types of oil are used as the medium. Unlike solids the thermal conductivity of liquids changes more drastically even for a small change in temperature as shown in Fig.2. More than 40̊C Olive oil shows a higher thermal conductivity in comparison to sunflower and corn oil.
However all three types of oil show decreasing thermal conductivity with increase in temperature as reported by Alpaslan Talgut and coworkers [8]

During the process of cooking, conduction, convection and radiation can take place at the same time. Conduction is observed within the utensil or food being cooked, convection within any liquid medium and radiation between the food and the surroundings. A combination of conduction, convection and radiation can also decide the process of cooking, for steamed food the conduction and convection are high, but the radiation is to be minimum. For boiling and frying the conduction and convection has to be high but radiation should be low. Fig 3 depicts the various processes of cooking and associated heat transfer as reported by Burr Zimmerman [9]. Microwave heat and frying has a higher heat transfer rate compared to other processes. Microwave cooking takes less time due to the high heat transfer process involved. Further it can be considered as cooking in which heat directly enters the food from the top against conventional cooking in which heat enters the food from the bottom.

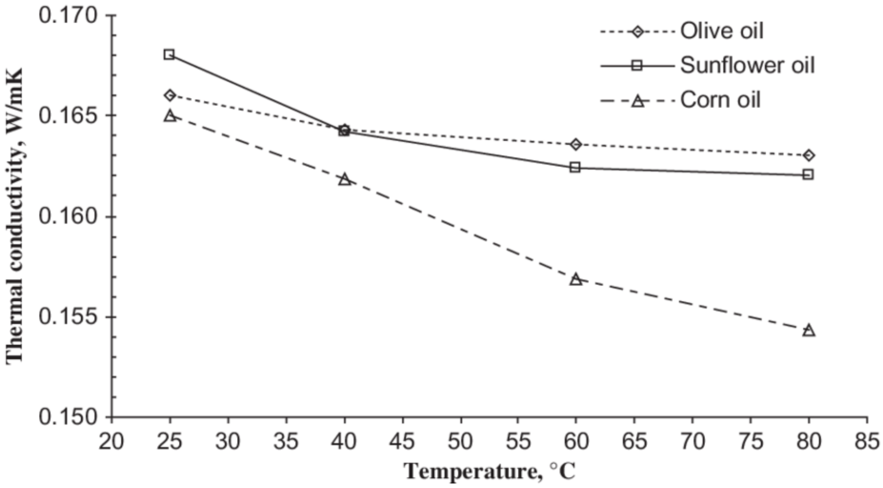

Figure 2. Variation of Thermal conductivity of oils used for cooking [2]

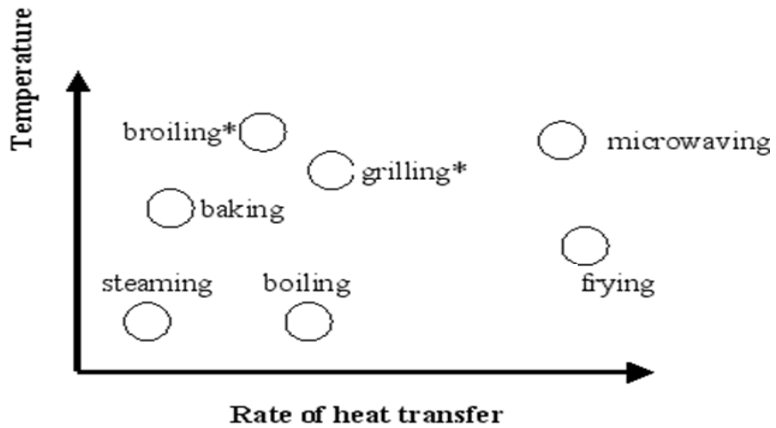

Figure 3. Various cooking processes and the rate of heat transfer

Density Changes During Cooking

Another important change during cooking is the change in density. It is interesting to note that certain foods like dumplings show the most significant change in density on cooking.The density changes from 1.19 to 0.92 Density of chicken decreased from 1.12 to 0.99. [10].Peanuts are an example in which the density increases after cooking.The density changes during cooking can be due to dehydration or water absorption.When an egg is boiled the density increases.This moment of inertia decreases due to the liquid solid phase transformation.The boiled egg will spin faster for the same amount of hand force given.Thus cooking can also affect the mass distribution of food .More amount of mass portion of the egg is close to the central axis of spinning of the egg after cooking.Unboiled eggs and boiled eggs can be used to demonstrate the law of conservation of angular momentum.Every egg has its own density (small variations).As an egg gets aged,the water content dehydrates and the density of egg decreases.Thus good egg sink and almost rotten eggs float on water.Knowledge of density can be used in food quality prediction.The drying process for fruits and vegetables are also explained by changes in true density and apparent density[11].Density variations can occur during the cooking stage by the formation of gel.Gelation can be formed during heating or cooling.Microstructural changes are also associated with cooking.They can be examined through scanning electron microscopy techniques.The variation of microstructural changes of starch in cooked wheat grains with temperature and time was investigated by Khongsak Srikaeo and coworkers [12].

CONCLUSION

Cooking can be considered as a multiple phase transformation process in which several factors like, time temperature, rate of heating, rate of cooling and ingredients determine the taste of food. Phase transformations are observed during cooking and phase change materials have been used to increase the efficiency of solar cells.Insulated solar energy cookers is being developed as a new technology for cooking which can minimize fossil fuels,reduce pollution and become an alternative to traditional cooking methodsChoosing proper technique of heat transfer and suitable medium for heat transfer can give desired product with less energy consumption.Having a knowledge of density changes can help us predict the quality of food products.

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