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HEAT TRANSFER AND MATERIALS IN COOKING

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ABSTRACT:

Heat transfer is a very important aspect in the cooking process. Heating food destroys potentially harmful bacteria and other microorganisms, which makes food safe to eat and easier to digest. When food or liquids become hot, their molecules absorb energy, begin vibrating rapidly, and start to bounce off of each other. As they collide, heat energy is produced and transferred, which warms and cooks our food. Heat transfer is the process of an item or substance coming into contact with a heat source and becoming hot. In more scientific terms, heat transfer is an exchange of thermal energy between two objects. There are three methods of heat transfer namely conduction, convention and radiation. All these methods are being used in cooking methods. Taste and healthiness of the food is our prime requirement. Does mode of heat transfer affect the test and Vitamins and other contents in the food? Various cooking method and their corresponding mode of heat transfer has been discussed and investigated all aspects concerned with the topic.

KEY WORDS: Cookware, Cooking methods, heat transfer in cooking

I. Introduction:

Human prime requirement of life to survive is food and water. Without food human can't survive. From the ancient period, human has been changing his food over the period. Historically, people secured food through two methods: hunting and gathering and agriculture. Today, the majority of the food energy required by the ever increasing population of the world is supplied by the food industry. Food is any substance consumed to provide nutritional support for the body. It is usually of plant or animal origin and contains essential nutrients such as carbohydrates, fats, proteins, vitamins, or minerals. The substance is ingested by an organism and assimilated by the organism's cells to provide energy, maintain life, or stimulate growth. Food safety and food security are monitored by agencies like the International Association for Food Protection, World Resources Institute, World Food Programme, Food and Agriculture Organization, and International Food Information Council. They address issues such as sustainability, biological diversity, climate change, nutritional economics, population growth, water supply, and access to food.

The right to food is a human right derived from the International Covenant on Economic, Social and Cultural Rights (ICESCR), recognizing the "right to an adequate standard of living, including adequate food", as well as the "fundamental right to be free from hunger". Most food has its origin in plants. Some food is obtained directly from plants; but even animals that are used as food sources are raised by feeding them food derived from plants. Cereal grain is a staple food that provides more food energy worldwide than any other type of crop. Corn (maize), wheat, and rice – in all of their varieties – account for 87% of all grain production worldwide. Most of the grain that is produced worldwide is fed to livestock.

Some foods not from animal or plant sources include various edible fungi, especially mushrooms. Fungi and ambient bacteria are used in the preparation of fermented and pickled foods like leavened bread, alcoholic drinks, cheese, pickles, kombucha and yogurt. Another example is blue-green algae such as Spirulina. Inorganic substances such as salt, baking soda and cream of tartar are used to preserve or chemically alter an ingredient.

Heat transfer is an important process which is being used for cooking the food. We can't just eat raw food harvested from plant because human digestion system is not so strong to digest it so we heat to food in proper form in order to sustain its healthiness and taste called cooking. Several methods of cooking has been evolved over the time by humans. Different topographical area peoples prefer different tastes of

the food and thus different cooking method. What is the effect of the cooking method on taste of the food as well as the content of the food is needed to be investigate. As there is heat transfer one has to investigate the cookware and its material. From pottery to microwave is the journey of cookware. What are the properties of the material used in cookware that supports better for cooking?

II. Cooking methods

In cooking, there are some basic methods of cooking that are used. These commonly used basic cooking methods are divided into two general groups. The groups are: Dry heat cookery methods and moist heat cookery methods. The methods of cooking are divided into these two groups because of the way food is cooked and the type of heat that is used. Let us have a look at the Dry Heat cookery methods.

1. Dry heat Cookery Methods

In dry heat cooking methods, the food being cooked does not use water to cook the food. The food is left dry and heat is applied to cook the food. Such methods of cooking are: baking, steaming, grilling, and roasting. When heat is applied to the food, the food cooks in its own juice or the water added to the food during its preparation evaporates during the heating process and this cooks the food. Heat is applied directly to the food by way of convection thus making the food to get cooked. The action or movement of air around the food cooks it. Let us now have a look at each of these cooking methods

a) Baking

Figure1. Baking product

In baking method of cooking, the food is cooked using convection heating. The food is put into an enclosed area where heat is then applied and the movement of heat within the confined space, acts on the food that make it get cooked.

b) Steaming

To steam food, water is added to a pot and then a stand is placed inside the pot. The water level should be under the stand and not above it. There is no contact between the food and the water that is added to the pot. Food is then placed on the stand and heat is applied. The hot steam rising from the boiling water acts on the food and the food gets cooked. It is the hot steam that cooks the food, as there is no contact between the food and the water inside the pot. This method of cooking for vegetables is very good as the food does not lose its flavor and much of the nutrients are not lost during the cooking.

c) Grilling

There are two methods of grilling that are used these days. One type of grilling is the one that is commonly used by the people in the village. This is when food is cooked over hot charcoal on an open fire. The food is placed on top of the burning charcoal. Sometimes people improvise by using wire mesh and place it over the open fire to grill fish or vegetables. The other method is using grills that are inbuilt in stoves. In this method, the griller, which has a tray, is heated up and the food is placed on the grill tray to cook. The heat can be gas-generated or electric-generated depending on the type of stove used. The food is again left to cook on the grill with the doors of the grill open. People who can afford to buy a stove would use the grilling part to grill their food. What happens in this type of cooking is the heat seals the outside part of the food and the juice inside the food cooks it. The flavor of the food is not lost and much of the nutrients are not lost either. Food is frequently turned over to prevent it from burning and to ensure that equal heating and cooking time is applied to both sides of the food. By doing this, the food is cooked evenly and thoroughly.

d) Roasting

With roasting, direct heat is applied to the food. The heat seals the outside part of the food and the juice inside the food cooks the food. Roasting is mainly used when cooking fleshy food like fish, meat or chicken. When heat is applied to the outer covering of the food, it seals it up thereby trapping all the juices inside the food. The action of direct heating, heats up the juices inside the food, which then cooks the food. Again there is very little nutrient lost and the flavor is not spoilt. Food is frequently rotated over the spit so that there is even heating applied to

all parts of the food. This is so that heat is applied evenly to the food to make it get cooked properly.

2. Moist Heat Cookery Methods

In moist heat cookery methods, liquid is used as a medium to cook the food. Such medium could be water, coconut cream or oil. These liquids are added to the food before heat is applied to it or sometimes heat is applied to the liquid before the food is added into the cooking utensils to be cooked. The moist heat cookery methods include: boiling, stewing, shallow frying, deep frying, barbequing and basting. All these moist heat cooking methods use liquid to cook the food in.

a) Boiling

This is the most common method of cooking and is also the simplest. With this method of cooking, enough water is added to food and it is then cooked over the fire. The action of the heated water makes the food to get cooked. The liquid is usually thrown away after the food is cooked. In the case of cooking rice, all the water is absorbed by the rice grains to make it get cooked. During the heating process, the nutrients can get lost or destroyed and the flavor can be reduced with this method of cooking. If you over cooked cabbage, all the nutrients can get lost.

b) Stewing

In the process of cooking using the stewing method, food is cooked using a lot of liquid. Different kinds of vegetables are chopped, diced or cubed and added to the pot. Sometimes pieces of selected meat, fish or chicken is also chopped and added to the stew. The liquid is slightly thickened and stewed food is served in that manner. This method is also used when preparing fruits that are going to be served as desserts. With this cooking method, every food is cooked together at the same time in one pot. The flavor, colors, shapes and textures of the different vegetables that are used, makes stewing a handy method of cooking. The only disadvantage is that some of the vegetables might be overcooked and thus the nutrient content becomes much less. It is therefore important that the vegetables that take the longest to cook to be put into the pot first and the ones that need least cooking to be put in last. In this way much of the nutrient contents of the food do not get lost.

c) Frying

When food is fried using oil or solid fat it is important that you observe some rules in handling oil or fat. Simple rules to follow when frying:

1. Make sure there is enough oil or fat put in the frying pan or a deep frying pan.

2. The food to be cooked must not have water dripping from it. This is because when water comes into contact with hot oil or fat, you will have the oil sizzling and spitting out of the pan, which could burn your skin if you are not careful.

3. Put the food into the hot oil carefully. Try not to make a big splash as the oil could burn your skin.

4. The oil of fat should be heated to the right temperature before putting food into the pan to be fried. If the food is put in when the oil or fat is not heated to the right temperature, the food will soak up the oil and you will have food that is all oily or greasy. If the oil or fat is over heated, you will end up with food that is burnt. Sometimes the food especially doughnuts will turn brown on the outside but the dough inside is uncooked. To cook food using the frying method, there are two ways of doing it. There is the shallow frying and the deep frying methods.

d) Shallow Frying

In shallow frying, food is cooked in a frying pan with a little amount of oil or fat. The oil or fat is heated to the correct amount and the food is put into the heated oil. The food is turned over a few minutes or is stirred around a couple of times before it is cooked and dished out. If patties, potato chips or coated foods are fried, it is best to put a piece of brown paper or paper napkin inside the tray to soak up any oil from the food before serving it.

e) Deep Frying

This is when a lot of oil or fat is used in cooking the food. The oil or fat is usually put into a deep pan and is heated to boiling point. Food is then put into the hot boiling oil and is cooked in that way. Such food as fish fingers, potato chips, meat balls, and dough nuts to name a few, are cooked using the deep frying method.

f) Barbequing

The method of cooking food by barbequing is usually associated with fund raising activities, parties or picnics. It is most suitable to cooking meat cutlets, fish or chicken pieces. The food is usually marinated with spices and tenderizers (for meat cuts) for some time before it is cooked. With this method of cooking, a sheet of metal with stands is heated up and oil is used to cook the food. A sufficient amount of oil is heated up and food is added. The food is then turned over a couple of times before it is dished out.

g) Basting

This method of cooking is usually associated with roasting. The juice or liquid that comes out of the meat being cooked is spooned over the roast frequently while it is being roasted. The outer part of the meat is moistened frequently during the cooking process with the juice that is being spooned over. Usually, the extra juice from the cooked meat is added to a mixture to make the meat sauce.

III. Tastes preferred by humans

Animals specifically humans have five different types of tastes: sweet, sour, salty, bitter, and umami. As animals have evolved, the tastes that provide the most energy (sugar and fats) are the most pleasant to eat while others, such as bitter, are not enjoyable.[14] Water, while important for survival, has no taste.[15] Fats, on the other hand, especially saturated fats, are thicker and rich and are thus considered more enjoyable to eat.

Sweet

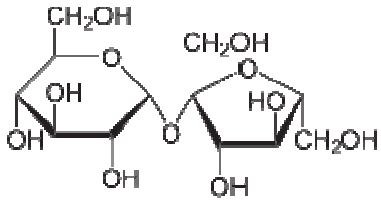

Figure1. Structure of sucrose

Generally regarded as the most pleasant taste, sweetness is almost always caused by a type of simple sugar such as glucose or fructose, or disaccharides such as sucrose, a molecule combining glucose and fructose.[16] Complex carbohydrates are long chains and thus do not have the sweet taste. Artificial sweeteners such as sucralose are used to mimic the sugar molecule, creating the sensation of sweet, without the calories. Other types of sugar include raw sugar, which is known for its amber color, as it is unprocessed. As sugar is vital for energy and survival, the taste of sugar is pleasant.

The stevia plant contains a compound known as steviol which, when extracted, has 300 times the sweetness of sugar while having minimal impact on blood sugar.[17]

Sour

Sourness is caused by the taste of acids, such as vinegar in alcoholic beverages. Sour foods include citrus, specifically lemons, limes, and to a lesser degree oranges. Sour is evolutionarily significant as it is a sign for a food that may have gone rancid due to bacteria.[18] Many foods, however, are slightly acidic, and help stimulate the taste buds and enhance flavor.

Salty


Figure2. Salt mounds in Bolivia

Saltiness is the taste of alkali metal ions such as sodium and potassium. It is found in almost every food in low to moderate proportions to enhance flavor, although to eat pure salt is regarded as highly unpleasant. There are many different types of salt, with each having a different degree of saltiness, including sea salt, fleur de sel, kosher salt, mined salt, and grey salt. Other than enhancing flavor, its significance is that the body needs and maintains a delicate electrolyte balance, which is the kidney's function. Salt may be iodized, meaning iodine has been added to it, a necessary nutrient that promotes thyroid function. Some canned foods, notably soups or packaged broths, tend to be high in salt as a means of preserving the food longer. Historically salt has long been used as a meat preservative as salt promotes water excretion. Similarly, dried foods also promote food safety.[19]

Bitter

Bitterness is a sensation often considered unpleasant characterized by having a sharp, pungent taste. Unsweetened dark chocolate, caffeine, lemon rind, and some types of fruit are known to be bitter.

Umami

Umami, the Japanese word for delicious, is the least known in Western popular culture but has a long tradition in Asian cuisine. Umami is the taste of glutamates, especially monosodium glutamate (MSG).[16] It is characterized as savory, meaty, and rich in flavor. Salmon and mushrooms are foods high in umami.

IV. Cookware and heat transfer

The purpose of cookware is to impart energy to ingredients. In America, the energy comes mainly in two forms: burning natural gas or propane gas and electrical resistivity. In both methods, the source of the heat is not uniformly spread over the pan. In a gas stove, the gas come out at regular intervals and forms a ring of individual flames. The heating elements of an electric range are designed to cover as much area as possible, but still have patterns (usually spirals) where there is no heat. Because the heat is not applied evenly, the cook must be aware of this and either compensate with cooking technique or through cookware.

High quality cookware should not only be durable, but also take the energy from the heat source and effectively transmit this energy to the ingredients. There are several factors that affect this capability. The two most important factors are thermal conductivity and heat capacity. Almost all discussions concerning the materials used in cookware are focused on these two factors.

Thermal conductivity

In short, the thermal conductivity of a material is how readily that material absorbs and transmits (releases) energy. When the fire or heating element of a range comes in contact to a pan, the energy from the heat source is transmitted to the pan. This increases the internal kinetic energy of the pan (commonly called "heating up"). The heated material then transmits the energy to nearby materials that are at a lower average molecular kinetic energy level (at a lower temperature than the material). The higher the thermal conductivity of the material, the faster it will heat up and also, the faster the heated area will spread to unheated areas of the same piece of material. For example, if we placed a large sheet of stainless steel (fairly low thermal conductivity as cooking materials go) on a burner and turned on the burner, the area directly under the burner would get hot while the rest of the sheet slowly heats up. The burner imparts heat quickly only to the region of steel directly over it. The rest of the pan heats up from the conduction of the heat from that spot. When the outer edges of the sheet have reached a hot temperature, the spot directly over the burner would be extremely hot. The figure below shows an example of the temperature of the sheet of steel over a gas burner. The hottest parts are shown in white, hot is red and cool is blue.

One solution to this problem is to make the sheet thicker. When heating a thick piece of steel (instead of a thin sheet), the bottom surface of the steel does not have the same temperature pattern as the top surface. Because the top surface is a greater distance from the heating element, the energy needs to conduct from the bottom to the top (just like the energy conducts outwards). The top surface of the steel is more evenly heated in this case. The figure below shows the thick sheet of steel after it has been sliced so the center of the front edge is where the burner heat touches the bottom of the sheet. The hot spot (white) is reduced by the time the heat conducts to the top surface of the sheet. Where the sheet is being heated, the temperature is more uniform now, but we still have uneven heating with this material. For this reason, the thicker the steel, the less variation in temperature on the top surface. Unfortunately, low thermal conductivity means it a lot of energy needs to be imparted to the bottom of the steel in order to get the top hot. So a pan made of a low thermally conductive material will take a longer time to reach cooking temperatures. In fact, materials with low thermal conductivity take longer to react to any change in temperature, so the thermal response of the pan would also be slow. (Thermal response is how quickly the surface temperature of the pan reacts to when we increase or decrease the flame of the burner.)

In most cooking applications, it is desirable to have the utensil heat up quickly, not develop hot spots, and react to changes we make to the range controls. Materials with high thermal conductivity fulfill our needs because they transmit heat quickly resulting in fast response to thermal changes and even distribution of the internal kinetic energy.

Here is a list of some common materials used in cookware and their respective thermal conductivity:

Material	Thermal conductivity
Copper	401 W/m*K
Aluminum	237 W/m*K
Cast Iron	80 W/m*K
Carbon steel	51 W/m*K
Stainless steel	16 W/m*K

Heat capacity

The amount of internal kinetic energy stored in a material can be referred to as it's heat capacity. This isn't the same thing as temperature, which is the average molecular kinetic energy within the material. For example, a kg of water at 100°F contains more energy than a kg of steel at 100°F. While thermal conductivity describes the materials ability to absorb energy, heat capacity is the amount of energy that is needed to raise or lower the temperature of the material. The molecular composition of some materials is such that as they absorb energy, much of it gets converted into potential energy and only a small amount increases the molecular kinetic energy (water is a common example). Other materials, like most metals, increase their molecular kinetic energy readily and do not store much of the absorbed energy as potential energy. The heat capacity of a material is proportional to its mass. So, a 2 kg piece of steel has double the heat capacity of a 1 kg piece of steel.

What this means is that cookware made of materials with high heat capacity, will take longer to heat up, but will also have a significant amount of energy stored up when it is hot. When energy is pulled out of the material, the temperature of the material will lower slowly when compared to materials with low heat capacity. Cast iron is often cited as an example of a high heat capacity cookware material. The specific heat (the heat capacity of a material for a given mass) of cast iron is half of aluminum's specific heat, but because cast iron cookware is generally several times the mass of aluminum cookware, it has a much higher *heat capacity.*

The thickness of metals used in the construction of cookware are often cited by the manufacturer (for example, 3 mm aluminum), but since heat capacity is a function of the mass of the material, density must be known to make comparisons between cookware of different materials.

Material	Specific Heat	Density
Aluminum	910 J/kg*K	2600 kg/m^3
Stainless Steel	500 J/kg*K	7500 - 8000 kg/m^3
Carbon Steel	500 J/kg*K	7500 - 8000 kg/m^3
Cast Iron	460 J/kg*K	7900 kg/m^3
Copper	390 J/kg*K	8900 kg/m^3

Looking at the table above, if you multiply specific heat with density, you'll find that the heat capacity per unit volume of steel, cast iron, and copper are about 1.5 times that of aluminum. This means, to achieve the same heat capacity in aluminum pan as in stainless steel pan, the aluminum pan needs to be 1.5 times as thick (assuming the other pan dimensions are the same).

Pulling it together: thermal diffusivity

Thermal conductivity alone does not determine how fast the pan will heat up (and also how evenly it will heat). In fact, the heat capacity plays a role in determining this as well. Wouldn't it be great if we had a single number that told us at what rate heat would transfer through and spread out in the material? There is, it's called the thermal diffusivity of a material and is simply the thermal conductivity divided by the unit heat capacity (specific heat times density). Let's take a look at how the materials stack up:

Material	Thermal diffusivity
Copper	$120 * 10^{-6}$ m^2/s
Aluminum	$100 * 10^{-6}$ m^2/s
Cast Iron	$22 * 10^{-6}$ m^2/s
Carbon Steel	$14 * 10^{-6}$ m^2/s
Stainless Steel	$4.3 * 10^{-6}$ m^2/s

Without additional calculations based on the heat conduction equation, there is very little that we can do with this table of values, except compare the materials against each other. It is clear, however, that the best performing materials (in terms of dishing out energy) are copper and aluminum. This leads us to our final consideration: reactivity.

Reactivity

Not only do we have to concern ourselves with the

thermal properties of materials, but we need to make sure that the materials we use in our cookware do not harm us or adversely affect the taste of our food (you decide which is worse). For this reason, in addition to the high thermal diffusivity, we would also like a non-reactive material. Unfortunately, both copper and aluminum react readily to foods. (Copper, when ingested in quantity or consistently, can cause liver, stomach, and kidney problems as well as anemia. Also, aluminum has long been suspected of contributing to Alzheimer's disease. Oh, every cookbook mentions, at this point in the discussion, that the occasional foamed egg white whipped in a copper bowl is not enough to harm you - but refrain from cooking every day on exposed copper.) Stainless steel, the least reactive of all popular materials used in cookware, also has the worst thermal diffusivity.

It seems that today, physics is not our friend. But, through the magic of cookware companies wanting to find ways to charge us lots of money, solutions have been devised to enable us to enjoy cookware made of materials with high thermal diffusivity and low reactivity. By combining the non-reactive surface of stainless steel with the thermal properties of copper or aluminum, you get the best of both worlds. There are several variations on this theme: steel- or tin-lined copper, stainless steel with aluminum or copper disk, stainless steel cladded aluminum, and stainless steel cladded copper. The table below summarizes my subjective assessment of the effectiveness of various material combinations (they are listed in order from most effective to least):

Rank	Composition	Comments
1	Copper with tin lining	Highest response; tin lining can be finicky can be susceptible to melting; copper exterior requires more care
2	Copper with stainless steel lining	Copper exterior requires more care but imparts the utensil with copper's excellent thermal properties
3	Aluminum with stainless steel lining	Thick aluminum provides excellent thermal response to thin steel interior
4		
	Copper fully clad by stainless steel	Copper layer may be thinner than copper with stainless steel lining; exterior and interior are durable and easy to maintain.

V. Advances in cooking technology

The category of cooking equipment is likely the area of the most growth in innovative applications. Everything from our ovens and griddles to steamers and fryers has received attention. These advances are often related to cost savings and product quality. Anytime we can approach advances in this manner it is better for the industry as well as the customer.

Oven Technology

The myriad of choices in the oven category can be confusing for some. The industry still offers the classic conventional and convection ovens, but oftentimes there are new aspects to the classic appliances. Combination (Combi) ovens from many manufacturers are now commonplace in many operations. The ability to use both steam and heat to cook, bake, prepare and re-thermalize foods offers both user and customer benefits. These systems can be programmed for certain food items and can be executed with the push of a button and sometimes paired with the insertion of a thermometer. Others offer impinged air (high speed heated air) features for quick cooking, while microwave to impinged air to facilitate a high speed cook for both baked goods and hot foods. Look for these advanced ovens from Alto-Shaam, Henny Penny, Ovention, OXO, Rational, and other manufacturers.

Blast Chill Technology

The ability to drop the temperature of a food product out of the danger zone does a few things.

1. Reduces the chance of bacteria growth which could cause foodborne illness.
2. Helps to retain moisture content resulting in a higher yield
3. Helps to maintain peak flavor

When we move into a blast freeze we are also helping to ensure product quality by the quick freeze of items, thus limiting the degradation of the products.

Cook-Chill Technology

The ability to cook and chill in the same piece of equipment is a time saving convenience. When the equipment works for you by going from cook to chill, this is a recognizable savings. This is accomplished through jacketed kettles and, on another level, with cook-chill cavities. In these processes you now have the product quality through the quick chill aspect and safety aspect of not having to move the product to and from a hot piece of equipment,both of which save labor. A top performer in this class is Irinox for blast chill, blast freeze, and cook-chill.

Steam Technology

Steaming of foods is being approached from a cost savings aspect. Steaming has progressed from boiler injected, to boilerless, and now to a PowerSteam or Steam Vector both from A ccuTe mp. These technologies cut both energy consumption and cook time. AccuTemp also manufactures steam jacketed kettles and has introduced a steam powered griddle. I had the opportunity to see the design and learn about the benefits of this griddle. It offers even and consistent heating from side to side, no hot spots, and it has a quicker recovery time for large cook loads.
In addition, it doesn't require chemicals to clean the cook surface, only water.

Hot Holding Technology

There are numerous ways to keep food hot for service. Your approach will be determined by your style of service. If you utilize a remote buffet that is loaded in the kitchen and set up in a different area, Burlodgeoffers a mobile holding unit that will keep food hot during transport and service on the buffet top. They also offer a tray cart that will allow you to tray both the hot and cold food, load it into a cart that is separated to keep hot food hot and cold food cold, and transport for ease and consistency of service. If you do plated meals, Aladdin Temp-Ritehas released their Heat on Demand system. This is a heated base that reaches temperature in 12 seconds. The base will heat a room temperature plate during plated food holding. The system offers over an hour of hot holding time.

VII. Conclusion:

There are number of cooking methods available to cook the food for us. But the heat required by the food to get cooked is important to be considered. The taste and preferences required by the peoples is one of the requirements then selection of cooking method decision can be made based on criteria's and requirement. Desired heat transfer should occur through the cookware used to cook the food. Different cookware's considering their thermal properties has been suggested in the paper. Maintaining desired taste, not losing its important contents and being most healthy is important for human's life.

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