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Computer Modeling of the Cooking Process for Pizza

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by

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Computer Modeling of the Cooking Process for Pizza

Introduction

Pizza places are very popular with American consumers. A recent consumer survey conducted by Restaurants and Institutions (Quinton, Lorenzini, & Townsend, 1990) ranked pizza places as the third most popular type of eating establishment. Pizza sales have increased by almost 55 percent between 1984 and 1989 (Anderson, 1991). Thus the pizza segment of the restaurant industry represents a significant part of the overall restaurant market. Like the rest of the segments of the market it is faced with many challenges ranging from anticipating changing consumer preference (Quinton et al., 1990) to finding a suitable site for expansion (Weinstein, 1987). The greatest challenges facing the industry, according to Gordon (1989), is the impending labor shortage. Labor woes and rising energy costs have forced the segment to seek ways to be more productive.

The pizza oven selected has a major impact on the quality of the finished product (Survey Results, 1989) and directly impacts productivity. It defines how many pizzas can be baked per hour, and how much attention they must receive during baking. Baking times have been significantly reduced due to the introduction of air impingement ovens that can cook in a fraction of the time it took conventional ovens. The newer ovens have different cooking zones so that the cooking process can be tailored to cook the pizza faster without excessive browning. However, even with the new high tech ovens, determining the exact baking time is still one of trial and error. This is a time consuming and expensive process.

The process could be shortened and costs reduced if a mathematical model could be developed to predict cooking times. The model must be easy to use and utilize data that can be collected without requiring the use of specialized equipment and sensors. The model would be of little value if it cost more to collect the needed data than to use the current trial and error method. Further, the necessity for complex data would make it impossible for the average pizza establishment to take advantage of the model.

The purpose of this study was to produce a model that could be used to determine baking times for cooking pizza. The model was to have utilize data that can be collected in the restaurant without specialized sensors. It was to have been accurate enough so that, even if it can't predict the exact cooking time due to the use of crude input data and the necessary assumptions, it will predict it close enough to eliminate most of the trial and error process. The model's chief use was to have been to optimize the baking process for new and existing pizza products.

Literature Review

The typical pizza consists of two separate components: a shell and the toppings (Lehmann & Dubois, 1980). Because of the differing composition and reactions that occur in each, they will be examined separately starting with the shell.

Shell

On average, the shell accounts for approximately 55 percent of the pizza, and is basically a thin, flat bread product (Lehmann & Dubois, 1980). There are two basic types of shells: thin, cracker-type and thick, deep-dish type. These two different classes of shells vary greatly in their characteristics and formulations. Probably the most significant variation is in the moisture content. The dough used for a thin shell can be made using as little as 55 grams of water per 100 grams of flour, while for the thicker shell as much as 70 grams of water per 100 grams of flour can used (Lehmann & Dubois, 1980). The amount of water in the shell significantly impacts the baking process. In addition to water, there are several other basic ingredients that are present in all pizza shells. The ingredients are: flour, salt, sugar, shortening or oil, and leavening agents (Lehmann & Dubois, 1980). Additionally several other ingredients are commonly found: milk solids and dough conditioners (Bruno, 1990). The amount of each ingredient varies greatly between the two classes of shells. It can even vary significantly between shells in the same class depending on the exact flavor and texture desired. For a better understanding of how varying the recipe creates the different types of shell, it is necessary to look at what each ingredient contributes.

The main ingredient is flour, it accounts for 51 to 62 percent of the dough (Lehmann & Dubois, 1980). Flour adds most of the nutritional value of the shell as well as binds the water. Further, it provides the structure and affects the taste of the finished product (Bruno, 1990). All purpose, enriched, white, wheat flour is composed chiefly of carbohydrate in the form of starch. It is composed of 76 percent carbohydrates, 11 percent protein, 3 percent fiber, 1 percent fat, and the remainder water (Whitney & Hamilton, 1987). The water binding capacity is due primarily to the starch and protein contents (Fennema, 1985). The proteins provide for much of the structure. Glutenins have the greatest effect on the structure. They are the proteins that form gluten and are responsible for the strength, elasticity, and cohesion properties of the dough (Fennema, 1985).

Water is the second most used ingredient. It counts for approximately 35 percent of the ingredients added, by weight (Lehmann & Dubois, 1980). It is impossible to make dough without using water. It makes the formation of gluten possible. It creates a dispersion of the other ingredients and binds the dough together (Bruno, 1990).

The remaining ingredients are added in small amounts when compared to the first two, but are just as necessary to ensure a proper shell. The first one of these ingredients is salt. It serves several roles in addition to flavoring the shell. It ties up water, stabilizes the fermentation, and strengthens the dough (Bruno, 1990). It strengthens the dough by reducing the repulsion forces between the dough components and by enhancing the interaction of the protein molecules (Pomeranz, 1987).

The next ingredients are shortenings and oils. This group of ingredients affects flavor, increases tenderness and dough elasticity, extends the shelf life of the dough (Bruno, 1990), and increases crust volume (Pomeranz, 1987).

Sugar, like shortenings and oils, also affects the flavor and tenderizes the dough. Further, it is important for yeast development and fermentation (Bruno,1990). Finally it is a necessary component for Maillard browning (Fennema, 1985).

Next comes the leavening agents, of which there are two classifications: yeasts and chemical agents (Lehmann & Dubois, 1980). The chief function of leavening agents are to provide for expansion of the dough, thus providing volume (Fennema, 1985). Yeast has the added function of contributing to the final flavor (Lehmann & Dubois, 1980). The yeast ferments the dough utilizing the sugar to form carbon dioxide, which causes the dough to expand, and alcohol, which affects the flavor (Fennema, 1985).

In some cases milk solids (powdered milk) are added to the dough. They add nutritional value to the shell, affect flavor, tenderize the dough, and increase volume and softness of the final product (Bruno, 1990) They may also contribute to browning because of their lysine (2 percent) and carbohydrate (38 percent) contents (Agricultural Research Service, 1976).

The final ingredients are a group of dough additives, also called dough conditioners. This is a group of chemicals that are added to the dough to improve elasticity, strengthen the dough, soften the crumb (the soft fluffy interior of bread products), and improve volume (Pomeranz, 1987).

Once all the ingredients have been assembled they are mixed. Glutens are formed during the mixing. If the glutens are not formed the shell will not rise properly (Pomeranz, 1987). Because of this it is important to control mixing time closely. Not enough mixing, and the gluten is not formed. Too much mixing is just as bad however, because it will produce a sticky dough that is hard to handle and will tear during the forming operation (Lehmann & Dubois, 1980). The chemically leavened dough can be formed after mixing, while the yeast leavened dough must be allowed to rise before forming (Lehmann & Dubois, 1980).

After the dough has been formed the yeast dough is allowed to rise a second time, then baked. The chemically leavened dough can be baked immediately after forming.

During baking the temperature of the dough rises causing crust and crumb formation. The following is a step by step account of the changes that occur as the shell heats.

40°C	Yeast activity increases (Pomeranz, 1987)
53°C	Starch gelatinization (irreversible swelling of the starch molecules) begins (Fennema, 1985)
58°C	Yeast killed (Pomeranz, 1987)
64°C	Gelatinization complete (Fennema, 1985)
70-80°C	Protein denatured resulting in loss of moisture (Fennema,1985)
95°C	Starch pasting (further swelling of the starch molecules at an elevated temperature, the viscosity of the dough is increased) occurs (Weaver, 1989)
100°C	Strong water vapor formation, final crumb volume and texture set, maximum crumb temperature (Pomeranz, 1987)
120°C	Browning begins (Pomeranz, 1987)
200°C	Charring begins (not desirable) (Pomeranz, 1987)

The crust is formed on the bottom when the moisture content of the crumb at the surface drops below the critical moisture content (the moisture content of the crumb when all the free moisture has been driven off). The temperature of the crumb will not rise until it has passed the critical moisture content. As the crust dries further its temperature rises to the point where browning can occur.

Browning is for the most part desirable, it provides for an appealing texture, color, and taste; however, it does detract slightly from the nutritional value of the shell by reducing the available lysine (Tsen, Bates, Wall, & Gehrke, 1982). A prediction of browning will not be included as part of this model due to its complex nature. The browning reaction is called the Maillard browning. To take place it must have a reducing sugar (like sucrose), a free amino group (from a protein like lysine), and water. It is known that the reaction is accelerated by heat, however, the exact reaction is not well defined (Fennema, 1985). Attempts to predict the surface browning of pizza shells has met with limited success and requires sophisticated analysis of the dough (Unklesbay, Unklesbay, Keller, & Grandcolas, 1983), something that is well beyond the purpose of this project.

Toppings

Although the topping accounts for 45 percent of the pizza weight, there is very little in the literature describing the movement of heat and moisture through it. Toppings consist primarily of a tomato based sauce, cheese, meats, and various fruits and vegetables (Lehmann & Dubois, 1980). The topping is the major flavor contributor to the pizza (Rossi, 1990). Aside from its flavor importance and cost, very little is written about toppings.

As toppings cook they release oils, water, and aromatic compounds. They also undergo texture change and loose nutritional value (due to denaturization of some vitamins). The following is a discussion, by topping, of those changes that occur at 100°C and below, and how those changes effect the cooking process for the pizza.

For the meat topping the main concerns center around the loss of water and oils. Water and oils leaving the topping can be absorbed by the dough, lengthening the cooking process. The protein in the meat begins to denature at 50°C (Fennema, 1985). It is at this temperature that the water begins to move from the meat. Fats can cause problems at even lower temperatures. The typical fats found in meats are 16 and 18 carbon chains. They can start to melt and leave the meat at temperatures less than 30°C (Fennema, 1985). One way to reduce the amount of moisture and fat migrating from the meat to the dough is to use precooked meats, which have already had some of the water and fat removed by cooking (Ingredients for Health, 1991).

The cheese on pizzas present many of the same problems as the meats. As they heat the proteins denature releasing moisture. Also, they tend to have relatively high fat contents, over 20 percent for mozzarella made with whole milk (Whitney & Hamilton, 1987). The migration of moisture and fat to the dough, lengthening the cooking process, can be reduced by using low-moisture, low-fat cheese (Anderson, 1991).

The vegetable toppings can also influence the cooking process of the shell. They have a high moisture content, and as they heat the cell walls rupture and the moisture is released. Some of these changes can be avoided by using products that have been sauteed or lightly cooked prior to being added to the pizza (Anderson, 1991).

Ovens

Equipment used to bake the pizza are called ovens (Kotschevar & Terrell, 1986). There are four basic types that can be classified based on the way they transfer heat to the pizza. They are deck, standard, convection, and air impingement.

Deck ovens heat by conduction and radiation. The pizza sits on a deck and heat is conducted up through the deck to the pizza. The upper surfaces are heated by radiated heat from the oven walls.

Standard ovens heat primarily by radiating heat from the walls of the oven. The air in the oven is still and very little heat is passed to the pizza by convection. In this type of oven the pizza sits on racks so that all sides are hit by the radiation.

Convection ovens combine radiation and convection to heat the pizza. As with the standard oven, the pizza sits on a rack and is hit on all sides by radiated heat. The difference between the two ovens is that in the convection oven air is blown across the pizza. The air movement increases the rate of heat transferred to the pizza, thus it cooks faster.

The final type is the air impingement oven. This type of oven is similar to the convection oven. The notable exception is that air is blown down on the pizza instead of across it. The air movement is typically much faster in an impingement oven. Air speeds are typically as high as 60 miles per hour. This is the fastest heating oven of the four types.

Heat Transfer in the Cooking Process

Heat moves by three means: conduction, convection and radiation. These three methods of heat transfer are well understood and standard equations have been developed (Geankoplis, 1978). As the heat moves through the product some of the heat is trapped in the product. The following discussion explains how heat moves through a product.

Conduction

Conduction is how heat moves through a solid object (Geankoplis, 1978), in this case the components of the pizza. For this to occur a driving force must be present (temperature difference) that overcomes a resistance (thermal conductivity) resulting in the flow of heat. The standard equation is:

$$q=(k/x)A(T_2-T_1)$$

where:

q is heat transferred

k is the thermal conductivity of the material

x is the distance between the two temperatures

A is the cross sectional area of the material

T_2 is the higher temperature

T_1 is the lower temperature

There are five variables in the above equation: k, x, A, T_2, and T_1. The values of these variables change constantly during the cooking process. The two temperature terms clearly change during the heating process. As the pizza heats, the temperature of the surface and the center change. The change in the other variables may not be quite as apparent as the temperature, however they do change just as surely.

The cross sectional area and the distance the heat travels (x) change for the same reasons. As part of the cooking process the physical dimensions of the pizza changes. The heat causes the shell to expand while at the same time driving off moisture from the topping causing some of the items to contract. Therefore, the dimensions of the product change during cooking.

The final variable, the thermal conductivity, changes because of the many changes taking place in the pizza as it cooks. Thermal conductivity of a substance depends on the physical makeup of the substance and can be estimated if the composition is known (Choi & Okos, 1986). The following equations can be used to estimate the thermal conductivity of food products.

$$k = X_p k_p + X_l k_l + X_c k_c + X_f k_f + X_a k_a + X_w k_w$$

$$k_p = 1.7881E^{-1} + 1.1958E^{-3}T - 2.7178E^{-6}T^2$$

$$k_l = 1.8071E^{-1} - 2.7604E^{-4}T - 1.7749E^{-7}T^2$$

$$k_c = 2.0141E^{-1} + 1.3874E^{-3}T - 4.3312E^{-6}T^2$$

$$k_f = 1.8331E^{-1} + 1.2497E^{-3}T - 3.1683E^{-6}T^2$$

$$k_a = 3.2962E^{-1} + 1.4011E^{-3}T - 2.9069E^{-6}T^2$$

$$k_w = 5.7109E^{-1} + 1.7625E^{-3}T - 6.7036E^{-6}T^2$$

where:

X_p is the mass fraction (the mass of the component divided by the mass of the entire product) of the protein component

X_l is the mass fraction of the fat component

X_c is the mass fraction of the carbohydrate component

X_f is the mass fraction of the fiber component

X_a is the mass fraction of the ash component

X_w is the mass fraction of the water component

k_p is the conductivity of protein at temperature T

k_l is the conductivity of fat at temperature T

k_c is the conductivity of carbohydrate at temperature T

k_f is the conductivity of fiber at temperature T

k_a is the conductivity of ash at temperature T

k_w is the conductivity of water at temperature T

T is the temperature in Celsius

The above equations can introduce an error of almost six percent and should only be used if experimental data is not available. This type of information will most likely not be available to the users of this model.

As the above equations clearly show the conductivity of the pizza is a function of its composition and temperature. As the pizza cooks moisture is lost and the composition changes thus changing the conductivity.

There are several problems with cooking pizzas that will introduce additional error to the above equations. First, the equations do not take into account all the chemical and physical changes occurring in the product; such as: protein denaturization and starch gelatinization. Also, the shell is a porous material. Heat will not flow through the gas pockets as readily as through the solid part, and since the exact arrangements of the gas pockets are not known, the exact path the heat will travel can not be determined (Wallapapan, Diehl, Sweat, & Engler, 1986).

Convection

Convection is similar to conduction in that heat moves from a higher temperature to a lower one (Geankoplis, 1978). In this case the transfer medium is a gas or a liquid moving past a solid object. Air impingement ovens use gas as the transfer medium. The term for the resistance to flow is the convective-heat transfer coefficient (h). The coefficient is determined by the type of gas or liquid, the surface of the solid, and the speed at which the fluid is moving. The general equation for predicting the heat transfer due to convection is:

$$q=Ah(T_2-T_1)$$

As with conduction the values of the variables will change during the cooking process. The air temperature (T_2) should remain constant, however for air impingement ovens with several temperature zones it can be varied throughout the cooking process. The surface temperature of the pizza (T_1) will vary throughout the cooking process as the pizza heats. The convective-heat transfer coefficient will also vary during the cooking process slightly. The convective-heat transfer coefficient changes as the surface temperature of pizza increases. This is because as the temperature of the surface increases so does the air in the boundary layer (the layer air at the surface of the pizza that is not moving at the same speed as the air entering the oven). As the boundary layer temperature increase, the properties of the air changes slightly resulting in a change in the convective-heat transfer coefficient.

It is always best to use values for the convective-heat transfer coefficient obtained experimentally, however if such values are not available, the convective-heat transfer coefficient can be estimated by the following equation (Kreith & Black, 1980):

$$h=(k_{air}/D) \times A \times .228 \times N_{Re}^{.731} \times N_{Pr}^{.333}$$

$$N_{Re}=\rho\ u\ D/v$$

where:

k_{air} is the conductivity of the air

D is the diameter of the pizza

N_{Re} is the Reynolds number

N_{Pr} is the Prandtl number

p is the density of the air

u is the air speed

v is the air viscosity

Convection can also occur as a result of steam condensing on a surface. This type of convection takes place inside the crumb of the pizza. Because of the large pores and the high water content, heat is moved through the crumb faster than can be expected if normal conduction was the mechanism by which the heat moved (Hallstrom, Skjoldebrand, & Tragardh, 1988). As the temperature of the crumb reaches 100°C water is vaporized. The vaporization takes place first at the side of the pore closest to the heat source. The vaporized water then moves to the cooler side to the pore where it condenses. Because of the high heat of vaporization for water, large amounts of heat can be moved across the pore very quickly. Thus heat is moved through the crumb very quickly.

Radiation

The final method of heat transfer is radiation. This is the energy that moves across open spaces in the form of energy waves, some of which are visible light (Geankoplis, 1978). The amount of heat transferred is related to the area being struck by the radiation, the temperature of the radiating and absorbing bodies, and how well the pizza can absorb the radiation. A material's ability to emit radiation is called its emissivity. How well it absorbs radiation is called its absorptivity. For a given temperature for a given surface the absorptivity is equal to the emissivity. The equation for heat transfer by radiation is:

$$q=A_1 C_{SB} e(T_1^4-T_2^4)$$

where:

A_1 is the area of the pizza exposed to the radiation

e is the emissivity of the pizza

C_{SB} is Stefan-Boltzmann constant

T_1 is the temperature of the pizza

T_2 is the temperature of the oven

Specific Heat

Not all heat that is moved into a body is passed smoothly through, some of the energy is retained in the body (Geankoplis, 1978). Heat moving into a body can be used to change the state of the material. An example of this is the melting of cheese or the vaporization of water. The material is also warmed as heat enters it. The amount of heat it takes to raise one gram of a substance one degree Celsius is called the specific heat and is symbolized by c_p.

If the specific heat is not known it can be estimated using the following equation (Choi & Okos, 1986):

$$C_p = X_p C_{pp} + X_l C_{pl} + X_c C_{pc} + X_f C_{pf} + X_a C_{pa} + X_w C_{pw}$$

$$C_{pp} = 2.0082 + 1.2089E^{-3}T - 1.3129E^{-6}T^2$$

$$C_{pl} = 1.9842 + 1.4733E^{-3}T - 4.8008E^{-6}T^2$$

$$C_{pc} = 1.5488 + 1.9625E^{-3}T - 5.9399E^{-6}T^2$$

$$C_{pf} = 1.8459 + 1.8306E^{-3}T - 4.6509E^{-6}T^2$$

$$C_{pa} = 1.0926 + 1.8896E^{-3}T - 3.6817E^{-6}T^2$$

$$C_{pw} = 4.1289 - 9.0864E^{-5}T - 1.3129E^{-6}T^2$$

Where:

C_{pp} is the specific heat of protein at temperature T

C_{pl} is the specific heat of fat at temperature T

C_{pc} is the specific heat of carbohydrate at temperature T

C_{pf} is the specific heat of fiber at temperature T

C_{pa} is the specific heat of ash at temperature T

C_{pw} is the specific heat of water at temperature T

T is the temperature in Celsius

The above equations should only be used in the absence of experimental values since they can introduce almost a six percent error.

In order for these equations to work for the shell the volume of gas in the pores must be taken into account. This can be done based on density of the shell compared to the calculated density of the shell, based on its composition, if it was solid, no pores. The density of the solid components of the shell can be estimated using the following equations (Choi & Okos, 1986):

$$p = X_p p_p + X_1 p_1 + X_c p_c + X_f p_f + X_a p_a + X_w p_w$$

$$p_p = 1.3299E^{3} - 5.1840E^{-1} T$$

$$p_1 = 9.2559E^{2} - 4.1757E^{-1} T$$

$$p_c = 1.5991E^{3} - 3.1046E^{-1} T$$

$$p_f = 1.3115E^{3} - 3.6589E^{-1} T$$

$$p_a = 2.4238E^{3} - 2.8063E^{-1} T$$

$$p_w = 9.9718E^{2} + 3.1439E^{-3} T - 3.7574E^{-3} t^{2}$$

Where:

p_p is the density of protein at temperature T

p_1 is the density of fat at temperature T

p_c is the density of carbohydrate at temperature T

p_f is the density of fiber at temperature T

p_a is the density of ash at temperature T

p_w is the density of water at temperature T

T is the temperature in Celsius

The above equations should only be used in the absence of experimental values since they can introduce almost a six percent error. With the density of the solid component and the total density the mass of the gas may be found, and this information used to calculate the specific heat for the shell.

Heat absorbed into the product is also used to change the state of several its component: the cheese and the water vaporizes. The amount of energy required to change a solid into a liquid (cheese melting) is called the latent heat of fusion and is symbolized by H_f. The energy required to change a liquid to a gas (water vaporizing) is called the latent heat of vaporization and is symbolized by H_v.

Moisture Transfer in the Cooking Process

The final part of this section deals with the transfer of moisture. Moisture moves through materials chiefly in two ways: capillary action and diffusion. Capillary action involves the movement of free water in the liquid form (Geankoplis, 1978). A good example is liquid being absorbed by a paper towel. Diffusion is more common in food products. One example of diffusion is the movement of water vapor through pizza crust (Hallstrom, Skjoldebrand, & Tragardh, 1988).

As with heat transfer there must be a driving force to overcome a resistance in order for diffusion to occur. The driving force can be the difference between the available water (water activity) of the pizza and the relative humidity of the air in the oven. For any product there is a relationship between the water activity and the moisture content of the product. This relationship is temperature dependent, and the resulting plot of moisture content versus water activity is called the sorption curve (Geankoplis, 1978). Since, as a product dries it must follow the sorption curve for its current temperature, this would be a good way to predict the moisture loss and the temperature rise in the crust as it loses water. However, to use this method the sorption curves for all temperatures experienced by the shell must be known, or at least predictable.

In bread products there are many ingredients that affect its water activity (Czuchajowska, Pomeranz, & Jeffers, 1989). This could complicate the prediction of the water activity and consequently the sorption curves. Prediction of the water activity of the crust as it bakes is simple; as the crust forms, its water activity is constantly 100 percent (Hallstrom, Skjoldebrand, & Tragardh, 1988). The challenge for the baking crust is to predict the sorption curve for the different temperatures at a water activity of 100 percent. There are many different method of estimating sorption curves. Chirife and Iglesias (1978) compiled 23 of the most commonly used methods in a Journal of Food Technology article, however, none of these equations can be used to predict sorption isotherms at water activities over 90 percent. Therefore, it is not possible to accurately predict the isotherms for the baking process, another method must be found.

Pressure differences between the product and the environment due to the formation of steam can also be used as the driving force. The following equation can be used to predict moisture loss (Geankoplis, 1972):

$$M = 18 \times D_{Aeff} \times (P_2 - P_1)/(z \times R \times T)$$

where:

M is the mass of water diffusing

18 is the molecular weight of water

$D_{A\,eff}$ is the effective diffusivity

$(P_2 - P_1)$ is the pressure drop

z is the distance the moisture diffuses

R is the universal gas constant

T is the temperature

The problem in using the above equation is that it assumes the diffusivity will remain constant, which it does not (Porter, McCormick, Lucas, & Wells, 1973). It is affected by the moisture content and temperature of the product, both of which change while baking. However, a reasonable approximation for the diffusivity can be obtained by averaging the diffusivity over the entire baking process.

Industry Challenges

There are many challenges facing the pizza industry; failure to meet any one of them can spell hard times for the industry. Since the success of any business depends heavily on its customers, this is a good place to start examining trends.

There are several important consumer trends of which the pizza industry must be aware. These include changing tastes and an increased interest in healthy foods. The reason for both trends can be found in the changing demographics of the nation. The American population is aging (Elder, 1987), the median age is expected to climb from 31.5 years in 1987 to 38.5 years by the year 2010. The 35 to 64 years old age group is expected to increase by 44.5

percent while those under 35 will increase by only 4.5 percent for the same period. The biggest change will be for those Americans over the age of 85. That group is expected to swell by 120.8 percent. There have been many studies relating age to eating habits. The amount an individual spends has been correlated with the persons age (Quinton et al., 1990) Older couples spend less per week on dining out than any other age group. Additionally, older Americans are more likely to be on a restrictive diet for health reasons. The next fastest growing group, ages 35 to 54, seems to be concerned about nutrition as well (Frumkin, 1990). Based on these demographic changes it is easier to see the driving force behind the current trends.

The first trend is changing consumer tastes. In addition to growing older, consumers are becoming more sophisticated (Elder, 1987). This increased sophistication has manifested itself in a desire for more diverse and interesting tastes. This is one trend that the industry is poised to exploit with an increasing number of exotic toppings available (Slomon, 1991). While the industry is poised to exploit this trend, it must scramble to meet the other major trend, increasing interest in nutrition.

Pizza has long been known to be a nutritional food with several serious drawbacks: it is high in cholesterol, fat, and sodium (Wall, 1990). All is not gloom and doom with regard to nutrition; however, it is possible to make pizza that meets the American Heart Association's guidelines and still taste good (Rowe, 1991). The shells can be made of whole wheat flour and canola oil with very little salt, if any (Wall, 1990). The Fat and cholesterol can be further reduced by using new no-fat, non-dairy mozzarellas, or by simply reducing the amount of cheese on the pizza (Rowe, 1991). Using raw, unprocessed vegetables can further lower fat, cholesterol, and sodium. Finally, meat substitutes (like surimi) and precooked meats can be used (Ingredients For Health, 1991). Precooking meats can reduce the fat levels by almost 50 percent. Surimi has only 27 percent of the calories, 18 percent of the cholesterol, and 3 percent of the fat of traditional pork sausage. It is important to understand consumer trends, but other challenges must be met if a pizza establishment is to survive, let alone succeed.

Current labor trends pose what some consider the greatest challenge facing the industry (Gordon, 1989). The labor force is projected to increase by 1.5 percent from 1989 to the year 2000 while the 16 to 25 year old group will decrease from 20 to 15 percent of the total population (Gordon, 1989). At the same time the total labor requirement for the nation is projected to increase by 21,000,000 jobs, which includes a 600,000 job rise in the food service industry. (Gordon, 1989) The total increase in available labor is projected to be 20,900,000 persons (Greenberg, 1988). This leaves a shortfall of 100,000 persons, even more if you include a factor for normal unemployment. Because of the low wages and working conditions the food service industry will likely be hard hit by the short fall. If a company is going to be successful it must find a way to meet its labor need. There are two general ways it can do this: increase the size of the labor pool or reduce its labor requirements.

To increase the labor pool, companies will have to turn their attention away from their usual sources of labor, 16 to 25 year old, and try to tap other, less conventional sources. These sources include youths, minorities, disabled persons, women, older workers, individuals in career transition, and lawfully authorized immigrants (Gordon, 1989).

The shrinking labor pool is not the only labor related problem. Employment costs have been rising steadily over the last few years. Employment costs have risen by almost 33 percent between 1981 and 1987 (U.S. Bureau of the Census, 1989).

Increasing the labor pool may not be enough, ways will have to be found to reduce labor requirements. The rising employment costs are a further encouragement to reduce labor requirements. Ways to reduce labor requirements include operational changes in preparation and serving procedures, purchasing labor in the form of pre-packaged products, and the use of high technology items such as computers and robots (Backas, Gotschall, & Townsend, 1989).

The final challenges are in the area of energy costs and waste management. Both areas must be carefully monitored because of rapidly rising costs. Energy costs have risen by almost 270 percent between the years 1970 and 1985 (U.S. Bureau of the Census, 1989). Waste management presents an even more pressing problem, particular for solid wastes. Land fills are reaching capacity, some states have less than five years of land fill capacity left (Sarasin, 1990). As land fills are closed other, often more expensive, disposal methods must be used.

Pizza is a very complicated food. The recipes vary greatly which makes predicting the cooking process very difficult; however by making a few assumptions it is possible to estimate the flow of moisture and heat through the pizza as it cooks. Having a computer model of the cooking process would aid great in designing new cooking times,which is currently being done by trial and error. The model could be used to help improve overall efficiency for pizza establishment; something is becoming more and more important to many operators In today's challenging world those that can not compete efficiently will be hard pressed to survive.

Methodology

The methodology was divided into two distinct parts. The first part dealt with the stated purpose of this study; the development of a computer model to estimate the cooking time for pizza. The second part was concerned with the data needed to run the model and how to collect it. This was the part intended to test the accuracy of the model.

Computer Model

The purpose of the model was to predict cooking time using data that can be easily collected by a restaurant operator utilizing a scale, ruler, stopwatch, and a thermometer. Because of the limits of the imposed by the ability of the proposed user's data collecting capability and the natural variability of the product several assumptions were necessary to write the program.

The first assumption was that both pizzas were cooked in the same oven and that cooking conditions for the new cooking time were not significantly different from those for the known cooking time. Cooking conditions include oven temperature, air speed and moisture content, pan and oil used, and final temperature of the dough sauce interface. Further, that the composition of the two pizzas was identical. The more cooking conditions vary, the less accurate are some of the other assumptions made in the construction of this model.

The second assumption was that the average diffusivity for steam moving through the crust was the same for both pizzas, and that it gave a good representation of the actual moisture movement throughout the baking process. This assumption was necessary because the determination of the exact diffusivity is not possible given the data for which this model must operate.

The next assumption was that all moisture lost by the shell passes through the bottom of the shell in the form of steam. Also, that no moisture left the pizza until the bottom of the pizza reaches 100°C. It was highly likely that some moisture loss occurred before 100°C was reached; however, that amount was insignificant when compared to moisture lost after the 100°C temperature was reached, because the crust heats so rapidly the 100°C is reached very quickly.

The next assumption dealt with moisture movement within the shell. As the moisture moves from the bottom of the shell a moisture profile will develop in the crumb directly next to the crust. To accurately predict the moisture curve it was necessary to know the rate of moisture movement through the crumb both by capillary action and diffusion. This information will not be available to those who will use this model, therefore an assumption on how moisture moves inside the shell was necessary. The model assumed that there was no water movement within the crumb, and that there was a break in the moisture curve. The crust and crumb were be assumed to be at their respective constant moisture content and that there was no transitions zone between the two. This assumption is not correct; however, it was necessary for the model to function properly, and should not have an adverse effect the results since the determination of the completeness of baking was based on temperature and not moisture profiles.

The void spaces in the shell was the subject of the following assumptions. It was assumed that the voids were completely filled with carbon dioxide at the start of the cooking process. Further that they remain filled with carbon dioxide until the temperature of the voids reach 100°C, at which time they became completely filled with steam. This assumption resulted in a small error in the calculated value for the specific heat and conductivity of the dough before it reached 100°C. Since most of the heat that moves through the pizza moves by steam convection once the shell starts to reach 100°C (Hallstrom, Skjoldebrand, & Tragardh, 1988), the errors introduced as a result of this assumption should have been insignificant.

Finally, it was assumed that no heat moved between the shell and toppings. Also, that any moisture lost by the toppings was absorbed by the crust and had to be accounted for in the heating of the crust. Further, that the sauce layer was so thin that for the baking calculation it was treated as part of the shell. The reasoning behind these assumptions was that the cooking time should be established for the longest cooking pizza, the one with the most toppings. Because of the higher specific heats of the materials in the toppings when compared to the crust it will not contribute significantly to the heating of the crust. Further, since most of the heat was transmitted through the crust as a steam front (Hallstrom, Skjoldebrand, & Tragardh, 1988), and that once the front reached the sauce the pizza was done cooking, the amount of heat that reaches the toppings by way of crust was insignificant.

Based on the above assumption, the computer model was written using the finite difference method (Geankoplis, 1978). By this method, the product was divided into different sections with a node at the center of each section. Heat and mass transfers was calculated based on the differences between the nodes. The closer the nodes are together, the more accurate the model. The shorter the time interval between calculations, the more accurate the model. Since the temperature of the shell at the sauce interface determines when the pizza is done, only the shell was modeled. Finally, since the shell diameter is so much greater than its thickness, radial transfer was ignored and a one dimensional model developed. The equations used by the model to calculate temperature and moisture movement through the shell were based on the heat and moisture equations presented in the literature review. Using the temperatures of the nodes at a particular time it was possible to predict the new temperature of a node after a particular period of time by balancing the heat entering the node with that leaving plus any accumulated. Heat can enter or leave the node by any of the three mechanisms: conduction, convection, or radiation. The radiation term only contributed to the heating of the outer most node of the pan. Convection occurred at the outer most node of the pan due to air movement and inside the shell by condensing steam. In addition to the above mention modes of transport, heat also left the shell in the form of steam diffusion. The final part of the equation calculated what was retained in the node. There were two ways that heat was retained in the node: by increased temperature and the formation of steam. Base on the above describe heat balance the following equation was developed and used in the model:

$$q_{k,in} + q_{h,in} + q_{s,in} + q_{r,in} = q_{k,out} + q_{s,out} + q_{ret}$$

$$q_{k,in} = (k/x)\ ({}_tT_{n-1} - {}_tT_n)$$

$$q_{h,in} = h\ (T_{air} - {}_tT_n)$$

$$q_{s,in} = m_{s,n-1}\ H_f$$

$$q_{r,in} = C_{SB}\ e\ (T_{oven}{}^4 - {}_tT_n{}^4)$$

$$q_{k,out} = (k/x)\ ({}_tT_n - {}_tT_{n+1})$$

$$q_{s,out} = m_{s,n} \, H_f$$

$$q_{ret} = \rho \, c_p \, x \, ({}_{t+1}T_n - {}_{t}T_n) + m_{s,ret}$$

where:

$q_{k,in}$ is the heat moving in by conduction

$q_{h,in}$ is the heat moving in by air convection

$q_{s,in}$ is the heat moving in by steam convection

$q_{r,in}$ is the heat moving in by radiation

$q_{k,out}$ is the heat moving out by conduction

$q_{s,out}$ is the heat moving out by steam conduction and diffusion

q_{ret} is the heat retained

k is the conductivity of the pizza

x is the thickness of the slice

${}_{t}T_{n-1}$ is the temperature at time t of the previous node

${}_{t}T_{n}$ is the temperature at time t of the node

${}_{t}T_{n+1}$ is the temperature at time t of the next node

$_{t+1}T_n$ is the temperature of the node after the next segment of baking time has passed

T_{oven} is the temperature of the oven

h is the convective-heat heat transfer coefficient

$m_{s,n-1}$ is the mass of steam from the previous node that condenses giving its heat to node n

$m_{s,n}$ is the mass of steam from node n that condenses giving its heat to the next node

$m_{s,ret}$ is the mass of steam retained

H_f is the heat of vaporization

e is the emissivity of the pizza

C_{SB} is Stefan-Boltzmann constant

p is the density of the dough

c_p is the specific heat of the dough

Not all modes of heat transfer apply to every node, but the equations do cover all situation. Which mode of transfer which applies to which node was determined by where the node was located, its temperature, and its moisture content.

Data Collection

Data collection began with the inspection of a pizza cooked by a process that was known to cook the pizza to the desired sauce interface texture. The determination of exactly when the pizza reached this state was made by removing the toppings of a cooked pizza and inspecting the top of the shell. The cooking time was then shortened until the shell was no longer completely cooked. The shortest time that cooked the pizza was used as the known cooking time in the model. The temperature at the sauce crumb interface was taken from that pizza immediately after cooking.

Once the cooking time was established, the cooked pizza was inspected for shell thickness, both precooked and cooked thickness were measured. The thickness of the crust was also measured on the cooked pizza. Weights were then determined using a new pizza that was cooked with a piece of foil separating the dough and sauce from the rest of the topping. First the pan was weighed, then the pan and oil. This gave a starting weight for the oil. The next weight was taken when the dough and sauce were in the pan. This gave the starting weight for the dough and sauce combination. Next the foil and remaining toppings were added, and the pizza was baked. Immediately after baking the foil was removed and any water that had pooled on top of the foil was collected and weighed. This weight was added to that of the dough since it was assumed that this water was absorbed by the dough. The final measurements involved weighing the pan, oil, dough, and sauce; then the pan and oil. These numbers were used to determine how much moisture was lost through the crust and how much oil was absorbed by the crust.

The remaining information needed by the model was the composition of both the sauce and dough. The compositions were estimated based on the respective recipes, and tables of food compositions published by the USDA (Agricultural Research Service, 1976).

The data used to verify the model's ability to accurately predict cooking time was collected for a single by Mitchell C. Henke at Lincoln Foodservice Products, Inc., 1111 North Hadley Road, Fort Wayne, Indiana. The data was collected using an air impingement oven. The oven was set at a temperature of 485°F with an air speed of 1300 feet per minute. The pan thickness was 1.9 millimeters. The exact ingredients in the dough and sauce were not known and had to be estimated to calculate the composition. The estimated compositions were based on french bread, adjusted for the moisture content of the pizza dough, and tomato sauce. The composition of the french bread and tomato sauce was taken from Understanding Nutrition (Whitney & Hamilton, 1987). Table 1 contains the values used to test the model.

Table 1. Composition of pizza ingredients

	Dough	Sauce
Protein	.082	.013
Carbohydrate	.438	.072
Fat	.034	.002
Fiber	.015	.013
Ash	.002	.010
Water	.340	.890

In addition to sauce the topping consisted of a layer of cheese followed by pepperoni, mushrooms, black olives, pork sausage, green peppers, onions, Italian sausage, and green olives.

The accuracy of the model was have been checked by using the data collected to estimate the cooking time for another oven setting for which the cooking time was known.

Results

The discussion of results is limited to the model, how it ran and a brief description of its main sections. The information on the data collected by Mr Henke is omitted because of its proprietary nature.

A successful run of the computer program was not achieved, although it appeared that the program would have succeeded if the run time was not so prohibitively long. The program took approximately 5 seconds to complete the temperature profile in the pizza shell for each change in time during the cooking process. Because the pizza was thin it had to be sliced very small to accurately predict the cooking action. The thin slices forced the time interval to be very small; approximately .04 seconds. The test run was made with the pizza divided into 190 slices. This number gave only three slices for the crust section. Since the crust section is where the moisture transfer occurs, it is desirable to slice it as thinly as possible to get a good picture of this very important action. Three slices were probably not enough for an accurate picture, but it should have given an approximation of what occurred in the crust. It would have required slightly under 12 hours to develop the initial temperature profile using an Epson Equity II+ personal computer if the crust was cut into three slices. Further, it would have required many more iterations to converge on the correct diffusivity and conductivity for the dough. It would have taken anywhere from 20 to well over

100 iterations to achieve conversion. This would have taken from 10 to 50 plus days of constant running just to estimate the parameters needed to predict the next cooking time. Because of the number of different cooking zones it would require several iterations to arrive at a good estimation of the next cooking time. This would have added at least several more days to the run time.

The following is a brief description of the part of the program for estimating the diffusivity and conductivity for the dough. The logic presented below would have worked for estimating the new cooking time; however, this part of the program was not completed because the run time test for the first part indicated that the usefulness of the program is very limited. The only difference is that the iterations would have been based on final temperature and run time as opposed to final temperature and moisture content.

The program begins by setting up a table for general information about air. This information is needed to calculate the convective-heat transfer coefficient for the air in the oven. The information includes the specific heat, conductivity, density, and viscosity for various air temperatures.

Lines numbered 100 through 4160 are the information gathering part of the program. They prompt the user for the necessary information to run the program. The information necessary to run the program is:

1. Dough composition

2. Sauce composition

3. Starting weights for the dough, sauce, and oil

4. Thickness of raw dough

5. Temperature of pizza before cooking

6. Final weight of bread and sauce, oil, and water from the toppings

7. Final thickness of the shell and crust

8. Final temperature at dough sauce interface

9. Information abut pan, including: thickness, diameter, density, conductivity, specific heat, and emissivity

10. Total cooking time

11. Number of cooking zones, and the temperature, length, and air speed or convective-heat transfer coefficient

12. Estimated diffusivity

13. Number of nodes in shell

Lines 4170 to 5140 convert supplied information into constants needed to run the program. These lines also establish the necessary arrays needed to track composition, temperature, and moisture loss.

Lines 5050 through 5260 reset constants between iterations.

Lines 5270 through 6925 are the heart of the program. They determine the temperature and compositional changes as the pizza bakes. They are divided into four main sections. The first deals with the heat moving to and through the pan and oil layer. The second covers heat moving to the surface of the dough. It also covers moisture loss from the first section and oil absorbed. The third part calculates what is occurring in the center of the dough. This includes moisture loss, oil absorption, as well as temperature rise and steam formation. The final section deals with the temperature rise at the sauce dough interface. All sections covering the dough, except the last one, are subdivided into parts based on the condition of the dough at the time of the calculation. The variables are the position of the node, (whether it is in the drying phase), the amount of steam filling the voids, the moisture content, and the temperature of the dough.

The final lines determine when the values calculated for the diffusivity and conduction terms are correct. They do this by first comparing the calculated moisture loss and the actual moisture loss, then the calculated final temperature with the actual final temperature. If either is off, the proper variable is adjusted and the program returns to line 5050 to reset the variables and run the calculations again.

The program makes use of several functions and a subroutine. The subroutine calculates the new composition of the dough after moisture loss. The "h" function calculates the convective-heat transfer coefficient for the oven utilizing the air speed in the oven. The "K" function calculates the conductivity for the dough. The "ROE" function calculates the density for the dough. Finally, function "SPHEAT" calculates the specific heat for the dough.

Conclusion

There is definitely a need for a way to predict pizza cooking times; although this attempt did not yield an acceptable model, it provides the first step. A program that can take as much as 50 days to run is not a significant improvement over the current trial and error method; especially when you consider that this program will only give an approximate cooking time. Trial and error will still have to be used to get the exact cooking time. However, the project did successfully advance the knowledge base and could satisfy the requirements of the industry once the run time is shortened.

Even if the run time for this program was shorter, this program would still have limitations. The most significant is the fact that it basically ignores what is happening to the toppings. The toppings are an integral part of the pizza. Limiting their contribution in the cooking process to the moisture remaining on a piece of aluminum foil at the end of the cooking process does not fully account for their importance to the cooking cycle. One goal of any attempt to model a cooking process is to gain a better understanding of the process. Ignoring the toppings and how they are affected by the process limits the educational benefit of the model. Further, even though there may be very little heat interaction between the shell and the toppings for a pizza with maximum toppings, this is not true for other pizzas (such as a cheese pizza). Therefore, this model would have given a good estimate of the cooking time for only those pizzas with a significant amount of toppings.

Another limitation centers around the movement of moisture and crust temperatures. Moisture is assumed to enter from the toppings and leave through the bottom only. It does not account for the moisture profiles, which will effect the movement of heat. Further, it does not account for any moisture that diffuses upward during cooking. Moisture could be leaving the crust by two paths, out the bottom and up through any exposed crust. By ignoring the possibility of moisture moving upward, the moisture content in the is under-estimated, as is the rate of crust development. This lack of information on crust development can introduce significant errors when estimating other cooking times.

The rate of moisture leaving the crust can be correlated with the temperature of the crust (Hallstrom, Skjoldebrand, & Tragardh, 1988). This correlation was beyond ability of this program to predict. Because accurate correlations were not achieved, accurate temperature profiles in the crust were not predicted. This brings up a very important limitation of the program, the prediction of browning. While accurate predictions of browning are difficult to achieve because of the complex way the reactants interact and the effect of temperature on the rate of the reaction (Unklesbay, Unklesbay, Keller, & Grandcolas, 1983), an accurate crust temperature could give a rough approximation for browning. Since excessive browning is not desirable, and since high temperatures that produce the rapid heating also can produce excessive browning, it is important to know how hot the crust is getting.

The final set of limitations for the model were not defined due to a lack of data. These limitations address oven temperature, air speed, and what constitutes a significant change in the cooking process. There is an oven temperature above which the product can not be cooked as well as an upper limit for the air speed. These limits will have to be determined experimentally, as will the definition of what is a significant change in the cooking process. The key assumption for the model was that changes in the cooking process between the known and the new cooking time will introduce errors into the model. Exactly how much change the model will tolerate is still unknown.

In spite of the limitations and the fact that a run was not completed, the information contained in the program provides a foundation on which a workable model could be built. One possible way to improve the program is to divide the pizza into sections, and have a different time interval for each section. This should help reduce the run time for the model since less sensitive areas of the dough, like the crumb, would undergo fewer calculations than the more sensitive crust area.

The most important step in further development of working model is the collection of data under varied cooking conditions. There is a great deal of information about the cooking process that is not fully understood. One area is crust diffusivity and development. If a better understanding of crust development of the shell can be found, then the temperature and moisture movement can be better approximated, improving the overall accuracy of the model.

In a related area, more information is needed on sorption isotherms for the crust. This information can only be collected experimentally. Without this information the problem with predicting crust temperatures will remain. Without temperatures there is no way to even guess as to the browning that is taking place. Any model that predicts cooking times without regard to browning does not provide adequate information to reliably predict the cooking time.

A final modification that can significantly benefit this model is the elimination of insignificant variables. This can be done using regression analysis once significant amounts of data concerning the cooking process have been collected. The benefits of reducing the number of variables are obvious: fewer variables in the calculation mean shorter run times.

The data that need to be collected to accomplish the above stated modifications to the proposed model include the following areas: crust development, as measured by crust thickness; diffusivity of the crust, as measured by moisture losses during cooking; the pressure inside the dough, based on steam temperature in the dough; the effect of temperature on the rate of crust development, and the effect of temperature on the diffusivity of the crust. As the model is further developed more data could be collected to further improve its accuracy. This information includes sorption curves and how varying the ingredients in the dough will affect the cooking process.

Future models should continue to look at just the shell until a reasonable method for estimating its cooking properties can be found. Once this is done, then the more complicated processes involved in baking the toppings can be addressed.

There are alternate ways to estimate the cooking time for pizza. One way is to ignore the internal resistance to heat flow and calculate the cooking time based on energy required to raise the pizza to proper temperature. Figure 1 shows the relationship between oven temperature, air speed, and cooking time. There is one serious flaw with this method, it does not take into account the variations in cooking temperature and times result in varying amounts of moisture loss. This makes this particular model very inaccurate. The only use of such a model would be therefore in giving very rough approximations as to cooking times. The graph in figure 1 shows the general affect of air speed and oven temperature on cooking times for any high moisture product, including pizza.

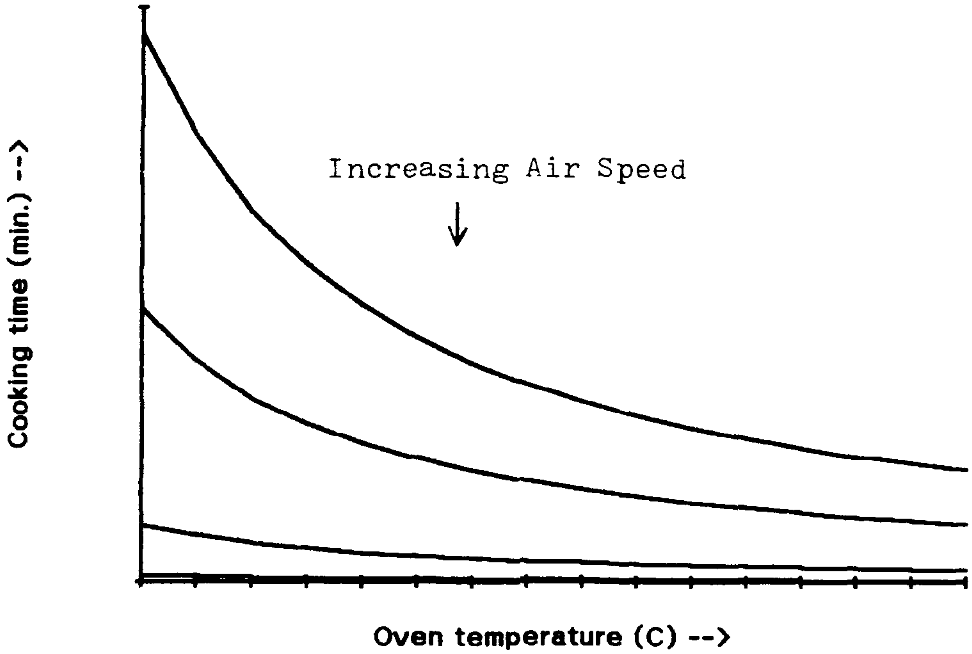

Figure 1. Relationship between air speed, oven temperature, and cooking time.

Although there are other ways to predict heat and moisture movement through a pizza, this research suggests that the finite difference method will be the one that finally yields an accurate model. The finite difference method allows the baking process to be broken into its elemental parts. While this will increase the computer run time, it permits the inclusion of all significant variables, thus providing the most accurate model. The finite difference method has other advantages as well. As the information base increases, this method allows the model to be easily updated. This allows it to benefit from any advancements in the area of crust development and browning prediction. A finite difference model can even be modified to include the heat and moisture movement in the toppings. The modifications of the model will improve its accuracy in predicting cooking times. As the accuracy of the model increases, so will the understanding of the cooking process. This increased understanding can lead to an improvements in the cooking process in terms of both process efficiency and reduced cooking times. An improved cooking process could significantly benefit the pizza industry by easing some of the current problems it is now facing; most notably are those problems in the areas of labor and energy costs. If the improved process significantly reduces the cooking time, then the oven capacities can be increased. This increased capacity could translate into improved efficiency by making the ovens and the people who operate them more productive. The increased productivity coupled with the expected improvements in the process efficiency should reduce the cost of making a pizza. The reduced per unit cost should improve the overall financial outlook for the industry.

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Appendix

Appendix 1: Notation

A is the cross sectional area of the material

A_1 is the area of the pizza exposed to the radiation

c_{pa} is the specific heat of ash at temperature T

c_{pc} is the specific heat of carbohydrate at temperature T

c_{pf} is the specific heat of fiber at temperature T

c_{pl} is the specific heat of fat at temperature T

c_{pp} is the specific heat of protein at temperature T

c_{pw} is the specific heat of water at temperature T

C_{SB} is Stefan-Boltzmann constant

D is the diameter of the pizza

D_{Aeff} is the effective diffusivity

e is the emissivity of the pizza

h is the convective-heat transfer coefficient

k is the thermal conductivity of the material

k_a is the conductivity of ash at temperature T

k_{air} is the conductivity of the air

k_c is the conductivity of carbohydrate at temperature T

k_f is the conductivity of fiber at temperature T

k_l is the conductivity of fat at temperature T

k_p is the conductivity of protein at temperature T

k_w is the conductivity of water at temperature T

M is the moles of water diffusing

$m_{s,n-1}$ is the mass of steam from the previous node that condenses giving its heat to node n

$m_{s,n}$ is the mass of steam from node n that condenses giving its heat to the next node

$m_{s,ret}$ is the mass of steam retained

N_{Pr} is the Prandtl number

N_{Re} is the Reynolds number

ρ is the density of the air

ρ_a is the density of ash at temperature T

ρ_c is the density of carbohydrate at temperature T

ρ_f is the density of fiber at temperature T

ρ_l is the density of fat at temperature T

ρ_p is the density of protein at temperature T

ρ_w is the density of water at temperature T

P_1 is the pressure at 1

P_2 is the pressure at 2

q is heat transferred

$q_{h,in}$ is the heat moving in by air convection

$q_{k,in}$ is the heat moving in by conduction

$q_{k,out}$ is the heat moving out by conduction

$q_{r,in}$ is the heat moving in by radiation

q_{ret} is the heat retained

$q_{s,in}$ is the heat moving in by steam convection

$q_{s,out}$ is the heat moving out by steam conduction and diffusion

R is the universal gas constant

T is the temperature

T_1 is the lower temperature

T_2 is the higher temperature

T_{oven} is the temperature of the oven

${}_tT_{n-1}$ is the temperature at time t of the previous node

${}_tT_n$ is the temperature at time t of the node

${}_tT_{n+1}$ is the temperature at time t of the next node

${}_{t+1}T_n$ is the temperature of the node after the next segment of baking time has passed

u is the air speed

v is the air viscosity

x is the distance between the two temperatures

X_a is the mass fraction of the ash component

X_c is the mass fraction of the carbohydrate component

X_f is the mass fraction of the fiber component

X_l is the mass fraction of the fat component

X_p is the mass fraction (the mass of the component divided by the mass of the entire product) of the protein component

X_w is the mass fraction of the water component

z is the distance the moisture diffuses

Appendix 2: Program

```
DECLARE FUNCTION K! (T!, SCOM!(), N!)
DECLARE FUNCTION SPHEAT! (T!, SCOM!(), N!)
DECLARE FUNCTION ROE! (T!, SCOM!(), N!)
DECLARE SUB NEWCOMP (PCMC!, SCOM!(), N!)
DECLARE FUNCTION h! (V!, T!, AIR!(), D!)
OPEN "A:AIR.DAT" FOR INPUT AS #1
OPEN "A:CO2.DAT" FOR INPUT AS #2
DIM AIR(10, 5)
DIM CO2(10, 3)
FOR N = 1 TO 10
INPUT #1, AIR(N, 1), AIR(N, 2), AIR(N, 3), AIR(N, 4), AIR(N,
5)
NEXT
FOR N = 1 TO 10
INPUT #2, CO2(N, 1), CO2(N, 2), CO2(N, 3)
NEXT
CLOSE #1
CLOSE #2


100     CLS
110     SCREEN 9
120     COLOR 1, 7
130     CLS
140     LOCATE 1, 18
150     PRINT "MODEL FOR ESTIMATING COOKING TIMES FOR PIZZA"
160     LOCATE 5, 5
170     PRINT "This program is for estimating the cooking
time for a pizza baked in a"
180     LOCATE 6, 5
190     PRINT "pan using oil.  Because of assumptions made
in the development of this"
200     LOCATE 7, 5
210     PRINT "program a new value for the diffusivity and
conductivity of the crust"
220     LOCATE 8, 5
230     PRINT "must be calculated for any significant
changes in cooking method."
240     LOCATE 10, 5
250     PRINT "Use the arrow key to select desired program
module."
260     LOCATE 12, 10
270     PRINT "( ) Determine the effective diffusivity and
conductivity of the crust"
280     LOCATE 14, 10
290     PRINT "( ) Estimate new cooking time"
300     LOCATE 12, 11
310     PRINT "X"
330     SELECT$ = INPUT$(1)
320     ROW = CSRLIN
340     IF ASC(RIGHT$(SELECT$, 1)) = 50 AND ROW = 13 THEN
342             LOCATE 12, 11
```

```
344            PRINT " "
350            LOCATE 14, 11
360            PRINT "X"
370            GOTO 330
380     ELSEIF ASC(RIGHT$(SELECT$, 1)) = 56 AND ROW = 15
THEN
382            LOCATE 14, 11
384            PRINT " "
390            LOCATE 12, 11
400            PRINT "X"
410            GOTO 330
420     ELSEIF ASC(RIGHT$(SELECT$, 1)) = 13 THEN
430            GOTO 470
440     ELSEIF ROW = 13 THEN
450               LOCATE 13, 11
460            GOTO 330
470     ELSE
480            LOCATE 15, 11
490            GOTO 330
500     END IF
510     IF ROW < 14 THEN
520            GOTO 560
530     ELSE
540            GOTO 10000
550     END IF
560     CLS
570     LOCATE 3, 25
580     PRINT "PARAMETER DETERMINATION MODULE"
590     VIEW PRINT 5 TO 25
600     LOCATE 5, 5
610     PRINT "COMPOSITIONS (in decimal form)"
620     LOCATE 7, 10
630     PRINT "DOUGH:"
640     LOCATE 8, 15
650     PRINT "PROTEIN:__________"
660     LOCATE 9, 15
670     PRINT "FAT:__________"
680     LOCATE 10, 15
690     PRINT "CARBOHYDRATE:__________"
700     LOCATE 11, 15
710     PRINT "FIBER:__________"
720     LOCATE 12, 15
730     PRINT "ASH:__________"
740     LOCATE 13, 15
750     PRINT "MOISTURE:__________"
760     LOCATE 15, 10
770     PRINT "SAUCE:"
780     LOCATE 16, 15
790     PRINT "PROTEIN:__________"
800     LOCATE 17, 15
810     PRINT "FAT:__________"
820     LOCATE 18, 15
830     PRINT "CARBOHYDRATE:__________"
840     LOCATE 19, 15
```

```
850     PRINT "FIBER:___________"
860     LOCATE 20, 15
870     PRINT "ASH:___________"
880     LOCATE 21, 15
890     PRINT "MOISTURE:___________"
900     LOCATE 8, 23, 1, 0, 7
910     INPUT "", IDPRO
920     LOCATE 8, 23
930     PRINT "           "
940     LOCATE 8, 23
950     PRINT IDPRO
960     LOCATE 9, 19, 1, 0, 7
970     INPUT "", IDFAT
980     LOCATE 9, 19
990     PRINT "           "
1000    LOCATE 9, 19
1010    PRINT IDFAT
1020    LOCATE 10, 28, 1, 0, 7
1030    INPUT "", IDCARBO
1040    LOCATE 10, 28
1050    PRINT "           "
1060    LOCATE 10, 28
1070    PRINT IDCARBO
1080    LOCATE 11, 21, 1, 0, 7
1090    INPUT "", IDFIBER
1100    LOCATE 11, 21
1110    PRINT "           "
1120    LOCATE 11, 21
1130    PRINT IDFIBER
1140    LOCATE 12, 19, 1, 0, 7
1150    INPUT "", IDASH
1160    LOCATE 12, 19
1170    PRINT "           "
1180    LOCATE 12, 19
1190    PRINT IDASH
1200    LOCATE 13, 24, 1, 0, 7
1210    INPUT "", IDMOIS
1220    LOCATE 13, 24
1230    PRINT "           "
1240    LOCATE 13, 24
1250    PRINT IDMOIS
1260    LOCATE 16, 23, 1, 0, 7
1270    INPUT "", ISPRO
1280    LOCATE 16, 23
1290    PRINT "           "
1300    LOCATE 16, 23
1310    PRINT ISPRO
1320    LOCATE 17, 19, 1, 0, 7
1330    INPUT "", ISFAT
1340    LOCATE 17, 19
1350    PRINT "           "
1360    LOCATE 17, 19
1370    PRINT ISFAT
1380    LOCATE 18, 28, 1, 0, 7
```

```
1390    INPUT "", ISCARBO
1400    LOCATE 18, 28
1410    PRINT "            "
1420    LOCATE 18, 28
1430    PRINT ISCARBO
1440    LOCATE 19, 21, 1, 0, 7
1450    INPUT "", ISFIBER
1460    LOCATE 19, 21
1470    PRINT "            "
1480    LOCATE 19, 21
1490    PRINT ISFIBER
1500    LOCATE 20, 19, 1, 0, 7
1510    INPUT "", ISASH
1520    LOCATE 20, 19
1530    PRINT "            "
1540    LOCATE 20, 19
1550    PRINT ISASH
1560    LOCATE 21, 24, 1, 0, 7
1570    INPUT "", ISMOIS
1580    LOCATE 21, 24
1590    PRINT "            "
1600    LOCATE 21, 24
1610    PRINT ISMOIS
1620    CLS 2
1630    LOCATE 5, 5
1640    PRINT "PREBAKING CONDITIONS"
1650    LOCATE 7, 10
1660    PRINT "WEIGHT OF RAW DOUGH (in grams):__________"
1670    LOCATE 9, 10
1680    PRINT "WEIGHT OF SAUCE (in grams):__________"
1690    LOCATE 11, 10
1700    PRINT "WEIGHT OF OIL IN PAN (in grams):__________"
1710    LOCATE 13, 10
1720    PRINT "THICKNESS OF SHELL (in
millimeters):__________"
1721    LOCATE 15, 10
1722    PRINT "TEMPERATURE OF PIZZA ENTERING OVEN (in
Celcius):__________"
1730    LOCATE 7, 41, 1, 0, 7
1740    INPUT "", PBDWT
1750    LOCATE 7, 41
1760    PRINT "            "
1770    LOCATE 7, 41
1780    PRINT PBDWT
1790    LOCATE 9, 37, 1, 0, 7
1800    INPUT "", PBSWT
1810    LOCATE 9, 37
1820    PRINT "            "
1830    LOCATE 9, 37
1840    PRINT PBSWT
1850    LOCATE 11, 42, 1, 0, 7
1860    INPUT "", PBOWT
1870    LOCATE 11, 42
1880    PRINT "            "
```

```
1890    LOCATE 11, 42
1900    PRINT PBOWT
1910    LOCATE 13, 46, 1, 0, 7
1920    INPUT "", PBDTH
1930    LOCATE 13, 46
1940    PRINT "          "
1950    LOCATE 13, 46
1960    PRINT PBDTH
1961    LOCATE 15, 58, 1, 0, 7
1962    INPUT "", TPIN
1963    LOCATE 15, 58
1964    PRINT "          "
1965    LOCATE 15, 58
1966    PRINT TPIN
1970    CLS 2
1980    LOCATE 5, 5
1990    PRINT "POST BAKING CONDITIONS"
2000    LOCATE 7, 10
2010    PRINT "WEIGHT OF OIL IN PAN (in grams):__________"
2020    LOCATE 9, 10
2030    PRINT "WEIGHT OF SHELL AND SAUCE (in
grams):__________"
2040    LOCATE 11, 10
2050    PRINT "WEIGHT OF WATER FROM TOPPINGS (in
grams):__________"
2060    LOCATE 13, 10
2070    PRINT "THICKNESS OF SHELL (in
millimeters):__________"
2080    LOCATE 15, 10
2090    PRINT "THICKNESS OF CRUST (in
millimeters):__________"
2091    LOCATE 17, 10
2092    PRINT "FINAL SAUCE TEMPERATURE (in
Celcius):__________"
2100    LOCATE 7, 42, 1, 0, 7
2110    INPUT "", BOWT
2120    LOCATE 7, 42
2130    PRINT "          "
2140    LOCATE 7, 42
2150    PRINT BOWT
2160    LOCATE 9, 47, 1, 0, 7
2170    INPUT "", BSSWT
2180    LOCATE 9, 47
2190    PRINT "          "
2200    LOCATE 9, 47
2210    PRINT BSSWT
2220    LOCATE 11, 51, 1, 0, 7
2230    INPUT "", BWWT
2240    LOCATE 11, 51
2250    PRINT "          "
2260    LOCATE 11, 51
2270    PRINT BWWT
2280    LOCATE 13, 46, 1, 0, 7
2290    INPUT "", BSTH
```

```
2300    LOCATE 13, 46
2310    PRINT "           "
2320    LOCATE 13, 46
2330    PRINT BSTH
2340    LOCATE 15, 46, 1, 0, 7
2350    INPUT "", BCTH
2360    LOCATE 15, 46
2370    PRINT "           "
2380    LOCATE 15, 46
2390    PRINT BCTH
2400    LOCATE 17, 47, 1, 0, 7
2410    INPUT "", TDSI
2420    LOCATE 17, 47
2430    PRINT "           "
2440    LOCATE 17, 47
2450    PRINT TDSI
2460    CLS 2
2470    LOCATE 5, 5
2480    PRINT "BAKING CONDITIONS"
2490    LOCATE 7, 10
2500    PRINT "PAN THICKNESS (in millimeters):__________"
2510    LOCATE 9, 10
2520    PRINT "PAN DIAMETER (in millimeters):__________"
2522    LOCATE 11, 10
2524    PRINT "PAN DENSITY (in kg/m"; CHR$(94);
"3):__________"
2530    LOCATE 13, 10
2540    PRINT "PAN CONDUCTIVITY (in watts/meter
Kelvin):__________"
2542    LOCATE 15, 10
2544    PRINT "PAN SPECIFIC HEAT (in J/kg K):__________"
2550    LOCATE 17, 10
2560    PRINT "EMISSIVITY OF PAN:__________"
2570    LOCATE 19, 10
2580    PRINT "TOTAL COOKING TIME (in seconds):__________"
2590    LOCATE 21, 10
2600    PRINT "NUMBER OF COOKING ZONES IN OVEN:__________"
2610    LOCATE 7, 41, 1, 0, 7
2620    INPUT "", PANTH
2630    LOCATE 7, 41
2640    PRINT "           "
2650    LOCATE 7, 41
2660    PRINT PANTH
2670    LOCATE 9, 40, 1, 0, 7
2680    INPUT "", PANDIA
2690    LOCATE 9, 40
2700    PRINT "           "
2710    LOCATE 9, 40
2720    PRINT PANDIA
2722    LOCATE 11, 34, 1, 0, 7
2724    INPUT "", PANDEN
2726    LOCATE 11, 34
2727    PRINT "           "
2728    LOCATE 11, 34
```

```
2729    PRINT PANDEN
2730    LOCATE 13, 51, 1, 0, 7
2740    INPUT "", PANCON
2750    LOCATE 13, 51
2760    PRINT "          "
2770    LOCATE 13, 51
2780    PRINT PANCON
2781    LOCATE 15, 40, 1, 0, 7
2782    INPUT "", PANSP
2783    LOCATE 15, 40
2784    PRINT "          "
2785    LOCATE 15, 40
2786    PRINT PANSP
2790    LOCATE 17, 28, 1, 0, 7
2800    INPUT "", PANEMIS
2810    LOCATE 17, 28
2820    PRINT "          "
2830    LOCATE 17, 28
2840    PRINT PANEMIS
2850    LOCATE 19, 42, 1, 0, 7
2860    INPUT "", TCOOKT
2870    LOCATE 19, 42
2880    PRINT "          "
2890    LOCATE 19, 42
2900    PRINT TCOOKT
2910    LOCATE 21, 42, 1, 0, 7
2920    INPUT "", NOZONES
2930    LOCATE 21, 42
2940    PRINT "          "
2950    LOCATE 21, 42
2960    PRINT NOZONES
2970    CLS 2
2980    LOCATE 5, 5
2990    PRINT " IS THE CONVECTIVE HEAT TRANSFER COEFFICIENT
FOR EACH ZONE KNOWN (Y/N)?"
3000    SELECT$ = INPUT$(1)
3100    IF SELECT$ = CHR$(89) THEN
3110            GOTO 3180
3115    ELSEIF SELECT$ = CHR$(121) THEN
3120            GOTO 3180
3125    ELSEIF SELECT$ = CHR$(78) THEN
3130            GOTO 3560
3135    ELSEIF SELECT$ = CHR$(110) THEN
3140            GOTO 3560
3150    ELSE
3160            GOTO 2970
3170    END IF
3180    DIM ZONET(NOZONES)
3190    DIM ZONEL(NOZONES)
3200    DIM ZONEh(NOZONES)
3210    M = 0
3220    CLS 2
3230    FOR N = 1 TO NOZONES
3240    M = M + 1
```

```
3250    LOCATE 5 + (M - 1) * 5, 5
3260    PRINT "ZONE:", N
3270    LOCATE 6 + (M - 1) * 5, 10
3280    PRINT "TEMPERATURE (C):__________"
3290    LOCATE 6 + (M - 1) * 5, 26, 1, 0, 7
3300    INPUT "", ZONET(N)
3310    LOCATE 6 + (M - 1) * 5, 26
3320    PRINT "          "
3330    LOCATE 6 + (M - 1) * 5, 26
3340    PRINT ZONET(N)
3350    LOCATE 7 + (M - 1) * 5, 10
3360    PRINT "LENGTH (mm):__________"
3370    LOCATE 7 + (M - 1) * 5, 22, 1, 0, 7
3380    INPUT "", ZONEL(N)
3390    LOCATE 7 + (M - 1) * 5, 22
3400    PRINT "          "
3410    LOCATE 7 + (M - 1) * 5, 22
3420    PRINT ZONEL(N)
3430    LOCATE 8 + (M - 1) * 5, 10
3440    PRINT "CONVECTIVE HEAT TRANSFER COEFFICIENT (W/m";
CHR$(94); "2 C):__________"
3450    LOCATE 8 + (M - 1) * 5, 57, 1, 0, 7
3460    INPUT "", ZONEh(N)
3470    LOCATE 8 + (M - 1) * 5, 57
3480    PRINT "          "
3490    LOCATE 8 + (M - 1) * 5, 57
3500    PRINT ZONEh(N)
3510    IF M = 4 THEN
3520            M = 0
3530            CLS 2
3540    END IF
3550    NEXT
3555    GOTO 3960

3560    DIM ZONET(NOZONES)
3570    DIM ZONEL(NOZONES)
3580    DIM ZONEh(NOZONES)
3590    DIM ZONES(NOZONES)
3600    M = 0
3610    CLS 2
3620    FOR N = 1 TO NOZONES
3630    M = M + 1
3640    LOCATE 5 + (M - 1) * 5, 5
3650    PRINT "ZONE:", N
3660    LOCATE 6 + (M - 1) * 5, 10
3670    PRINT "TEMPERATURE (C):__________"
3680    LOCATE 6 + (M - 1) * 5, 26, 1, 0, 7
3690    INPUT "", ZONET(N)
3700    LOCATE 6 + (M - 1) * 5, 26
3710    PRINT "          "
3720    LOCATE 6 + (M - 1) * 5, 26
3730    PRINT ZONET(N)
3740    LOCATE 7 + (M - 1) * 5, 10
3750    PRINT "LENGTH (mm):__________"
```

```
3760    LOCATE 7 + (M - 1) * 5, 22, 1, 0, 7
3770    INPUT "", ZONEL(N)
3780    LOCATE 7 + (M - 1) * 5, 22
3790    PRINT "                  "
3800    LOCATE 7 + (M - 1) * 5, 22
3810    PRINT ZONEL(N)
3820    LOCATE 8 + (M - 1) * 5, 10
3830    PRINT "AIR SPEED IN THE OVEN (m/s):__________"
3840    LOCATE 8 + (M - 1) * 5, 38, 1, 0, 7
3850    INPUT "", ZONES(N)
3860    LOCATE 8 + (M - 1) * 5, 38
3870    PRINT "                  "
3880    LOCATE 8 + (M - 1) * 5, 38
3890    PRINT ZONES(N)
3900    ZONEh(N) = h(ZONES(N), ZONET(N), AIR(), PANDIA)
3910    IF M = 4 THEN
3920            M = 0
3930            CLS 2
3940    END IF
3950    NEXT
3960    CLS 2
3970    LOCATE 5, 5
3980    PRINT "ESTIMATE FOR THE EFFECTIVE DIFFUSIVITY "
3990    LOCATE 6, 5
4000    PRINT "FOR THE CRUST (cm"; CHR$(94);
"2/s):__________"
4010    LOCATE 6, 28, 1, 0, 7
4020    INPUT DEFF
4030    LOCATE 6, 28
4040    PRINT "                  "
4050    LOCATE 6, 28
4060    PRINT DEFF
4070    LOCATE 10, 5
4080    PRINT "THE FINISHED SHELL THICKNESS IS  "; BSTH;
"mm"
4090    LOCATE 11, 5, 1, 0, 7
4100    PRINT "HOW MANY SECTION IS IT TO BE DIVIDED INTO?
__________"
4110    LOCATE 11, 48
4120    INPUT "", NODE
4130    LOCATE 11, 48
4140    PRINT "                  "
4150    LOCATE 11, 48
4160    PRINT NODE
4170    NODE = NODE + 1
4180    PCX = PBDTH / BSTH
4185    DX = (BSTH / 1000) / (NODE - 1)
4190    DIM SCOM(6, NODE)
4210    DIM STEMP(2, NODE)
4220    FOR N = 1 TO NODE
4222            SCOM(1, N) = IDPRO
4224            SCOM(2, N) = IDFAT
4226            SCOM(3, N) = IDCARBO
4228            SCOM(4, N) = IDFIBER
```

```
4230            SCOM(5, N) = IDASH
4232            SCOM(6, N) = IDMOIS
4234            STEMP(1, N) = TPIN
4236    NEXT
4237    TPAN1 = TPIN
4238    TPAN2 = TPIN
4240    VOLI = (PBDTH / 1000) * 3.141593 * (PANDIA / 2000) ^
2
4250    VOLC = (BCTH / 1000) * 3.141593 * (PANDIA / 2000) ^
2
4260    PAIR = (VOLI - ((PBDWT / 1000) / ROE(TPIN, SCOM(),
1))) / VOLI
4270    MLOSS = PBDWT - BSSWT + BWWT + PBSWT * ISMOIS -
(PBOWT - BOWT)
4280    IMOISC = VOLC * (PBDWT / (VOLI * (1 - PAIR))) *
IDMOIS
4290    IPROC = VOLC * (PBDWT / (VOLI * (1 - PAIR))) * IDPRO
4300    IFATC = VOLC * (PBDWT / (VOLI * (1 - PAIR))) * IDFAT
4310    ICARBOC = VOLC * (PBDWT / (VOLI * (1 - PAIR))) *
IDCARBO
4320    IFIBERC = VOLC * (PBDWT / (VOLI * (1 - PAIR))) *
IDFIBER
4330    IASHC = VOLC * (PBDWT / (VOLI * (1 - PAIR))) * IDASH
4340    FMOISC = IMOISC - MLOSS
4350    FOILC = IFATC + (PBOWT - BOWT)
4360    FMCC = FMOISC / (FMOISC + FOILC + IPROC + ICARBOC +
IFIBERC + IASHC)
4370    FOCC = FOILC / (FMOISC + FOILC + IPROC + ICARBOC +
IFIBERC + IASHC)
4380    FPCC = IPROC / (FMOISC + FOILC + IPROC + ICARBOC +
IFIBERC + IASHC)
4390    FCCC = ICARBOC / (FMOISC + FOILC + IPROC + ICARBOC +
IFIBERC + IASHC)
4400    FFCC = IFIBERC / (FMOISC + FOILC + IPROC + ICARBOC +
IFIBERC + IASHC)
4410    FACC = IASHC / (FMOISC + FOILC + IPROC + ICARBOC +
IFIBERC + IASHC)
4420    DIM OIL(6, 1)
4430    FOR N = 1 TO 6
4440            OIL(N, 1) = 0
4450    NEXT
4460    OIL(2, 1) = 1
4470    DIM MCDV(NODE)
4475    DIM MSIV(NODE)
4480    MCDVI = ((PBDWT / 1000) / VOLI) * (1 - PAIR) * (DX *
PCX) * IDMOIS
4490    MOILADD = ((PBOWT - BOWT) / 1000) / (BCTH / 1000) *
DX
4500    MCDVF = MCDVI - ((MLOSS / 1000) / (BCTH / 1000) *
DX)
4510    MSF = .5228 * DX
5000    LENGTH = 0
5010    FOR N = 1 TO NOZONES
5020            LENGTH = LENGTH + ZONEL(N)
```

```
5030    NEXT
5040    BSPEED = TCOOKT / LENGTH
5050    COOKT = 0
5055    OUTNODE = 1
5060    ML = 0
5070    MO = PBOWT / 1000
5075    FOR N = 1 TO NODE
5076            MSIV(N) = 0
5077    NEXT
5078    EHTNN = 0
5080    FOR N = 1 TO NODE
5090            IF N = 1 THEN
5100                    MCDV(N) = MCDVI / 2
5110            ELSEIF N = NODE THEN
5120                    MCDV(N) = MCDVI / 2
5130            ELSE
5140                    MCDV(N) = MCDVI
5150            END IF
5155    NEXT
5160    FOR N = 1 TO NODE
5170            SCOM(1, N) = IDPRO
5180            SCOM(2, N) = IDFAT
5190            SCOM(3, N) = IDCARBO
5200            SCOM(4, N) = IDFIBER
5210            SCOM(5, N) = IDASH
5220            SCOM(6, N) = IDMOIS
5230            STEMP(1, N) = TPIN
5240    NEXT
5250    TPAN1 = TPIN
5260    TPAN2 = TPIN
5270    FOR COOKT = 1 TO TCOOKT
5275    COOKL = 0
5280    FOR N = 1 TO NOZONES
5290            COOKL = COOKL + ZONEL(N)
5300            IF COOKT <= COOKL * BSPEED THEN
5310                    Zh = ZONEh(N)
5320                    ZONETEMP = ZONET(N)
5330                    EXIT FOR
5340            END IF
5350    NEXT
5360    TPAN1DT = TPAN1 + ((Zh * (ZONETEMP - TPAN1)) -
((PANCON / (PANTH / 1000)) * (TPAN1 - TPAN2)) + (PANEMIS *
5.67E-08 * ((ZONETEMP + 273.15) ^ 4 - (TPAN1 + 273.15) ^
4))) * (2 / ((PANTH / 1000) * PANDEN * PANSP))
5370    OILT = (TPAN2 + STEMP(1, 1)) / 2
5380    OILD = ROE(OILT, OIL(), 1)
5390    OILTH = (MO / OILD) / (3.141493 * (PANDIA / 2000) ^
2)
5395    IF OILTH <= 0 THEN
5396            DEFF = 2 * DEFF
5397            EXIT FOR
5398    END IF
5400    TPAN2DT = TPAN2 + ((PANCON / (PANTH / 1000)) *
(TPAN1 - TPAN2) - (K(OILT, OIL(), 1) / OILTH) * (TPAN2 -
```

```
STEMP(1, 1))) / ((PANTH / 1000) * PANDEN * PANSP + (OILTH /
2) * OILD * SPHEAT(OILT, OIL(), 1))
5410    IF STEMP(1, 1) < 100 THEN
5420            KOIL = K(OILT, OIL(), 1)
5430            SPOIL = SPHEAT(OILT, OIL(), 1)
5440            ROED = ROE(STEMP(1, 1), SCOM(), 1) * (1 -
PAIR)
5450            KD = K(STEMP(1, 1), SCOM(), 1) * (1 - PAIR)
* KEFF
5460            SPD = SPHEAT(STEMP(1, 1), SCOM(), 1) * (1 -
PAIR)
5470            STEMP(2, 1) = ((KOIL / OILTH) * (TPAN2 -
STEMP(1, 1)) - (KD / (DX * PCX)) * (STEMP(1, 1) - STEMP(1,
2))) / (((DX * PCX) / 2) * ROED * SPD)
5475    ELSE
5476            EHTNN = 0
5480    END IF
5490    IF STEMP(2, 1) > 100 THEN
5500            Q = (STEMP(2, 1) - 100) * ((DX * PCX) / 2) *
ROED * SPD
5510            STEMP(2, 1) = 100
5530            MSP = Q / 2444900
5540            IF (MSP + MSIV(1)) > MSF THEN
5550                    IF (MCDV(1) - (MSP + MSIV(1) - MSF))
< MCDVF THEN
5560                            EHTNN = (MCDVF - (MCDV(1) -
(MSP + MSIV(1) - MSF))) * 2444900
5570                            ML = ML + (MCDV(1) - MCDVF)
5580                            MCDV(1) = MCDVF
5590                            MO = MO - MOILADD / 2
5600                            OUTNODE = 2
5610                            SCOM(1, 1) = FPCC
5620                            SCOM(2, 1) = FOCC
5630                            SCOM(3, 1) = FCCC
5640                            SCOM(4, 1) = FFCC
5650                            SCOM(5, 1) = FACC
5660                            SCOM(6, 1) = FMCC
5670                    ELSE
5680                            PCMC = (MCDV(1) - (MSP +
MSIV(1) - MSF)) / MCDV(1)
5690                            ML = ML + (MSP + MSIV(1) -
MSF)
5700                            MCDV(1) = MCDV(1) - (MSP +
MSIV(1) - MSF)
5710                            CALL NEWCOMP(PCMC, SCOM(),
1)
5720                            MSIV(1) = MSF
5725                            EHTNN = 0
5730                    END IF
5740            ELSE
5750                    MSIV(1) = MSP + MSIV(1)
5755                    EHTNN = 0
5760            END IF
5770    END IF
```

```
5780    IF STEMP(1, 1) = 100 THEN
5790            KOIL = K(OILT, OIL(), 1)
5800            SPOIL = SPHEAT(OILT, OIL(), 1)
5810            ROED = ROE(STEMP(1, 1), SCOM(), 1) * (1 -
PAIR)
5820            KD = K(STEMP(1, 1), SCOM(), 1) * (1 - PAIR)
* KEFF
5830            SPD = SPHEAT(STEMP(1, 1), SCOM(), 1) * (1 -
PAIR)
5840            STEMP(2, 1) = ((KOIL / OILTH) * (TPAN2 -
STEMP(1, 1)) - (KD / (DX * PCX)) * (STEMP(1, 1) - STEMP(1,
2))) / (((DX * PCX) / 2) * ROED * SPD)
5850            IF MCDV(1) > MCDVF THEN
5870                    Q = (STEMP(2, 1) - 100) * ((DX *
PCX) / 2) * ROED * SPD
5880                    STEMP(2, 1) = 100
5900                    MSP = Q / 2444900
6000                    IF MSP + MSIV(1) > MSF THEN
6010                            IF (MCDV(1) - (MSP + MSIV(1)
- MSF)) < MCDVF THEN
6020                                    EHTNN = (MCDVF -
(MCDV(1) - (MSP + MSIV(1) - MSF))) * 2444900
6030                                    ML = ML + (MCDV(1) -
MCDVF)
6040                                    MCDV(1) = MCDVF
6050                                    MO = MO - MOILADD /
2
6060                                    OUTNODE = 2
6070                                    SCOM(1, 1) = FPCC
6080                                    SCOM(2, 1) = FOCC
6090                                    SCOM(3, 1) = FCCC
6100                                    SCOM(4, 1) = FFCC
6110                                    SCOM(5, 1) = FACC
6120                                    SCOM(6, 1) = FMCC
6130                            ELSE
6140                                    PCMC = (MCDV(1) -
(MSP + MSIV(1) - MSF)) / MCDV(1)
6150                                    ML = ML + (MSP +
MSIV(1) - MSF)
6160                                    MCDV(1) = MCDV(1) -
(MSP + MSIV(1) - MSF)
6170                                    CALL NEWCOMP(PCMC,
SCOM(), 1)
6180                                    MSIV(1) = MSF
6185                                    EHTNN = 0
6190                            END IF
6200                    ELSE
6210                            MSIV(1) = MSP
6215                            EHTNN = 0
6220                    END IF
6225            ELSE
6226                    EHTNN = 0
6230            END IF
6240    END IF
```

```
6250     FOR M = 1 TO NODE - 1
6260             M1 = M - 1
6270             M2 = M + 1
6290             ROED = ROE(STEMP(1, M), SCOM(), M) * (1 -
PAIR)
6300             KD = K(STEMP(1, M), SCOM(), M) * (1 - PAIR)
* KEFF
6310             SPD = SPHEAT(STEMP(1, M), SCOM(), M) * (1 -
PAIR)
6320             STEMP(2, M) = STEMP(1, M) + ((KD / (DX *
PCX)) * (STEMP(1, M1) + STEMP(1, M2) - 2 * STEMP(1, M)) +
EHTNN) / ((DX * PCX) * ROED * SPD)
6330             IF OUTNODE <> M THEN
6340                     IF STEMP(2, M) > 100 THEN
6350                             Q = (STEMP(2, M) - 100) * DX
* ROED * SPD
6360                             STEMP(2, M) = 100
6370                             MSP = Q / 2444900
6380                             IF (MSP + NSIV(M)) > MSF
THEN
6390                                     EHTNN = ((MSP +
MSIV(M)) - MSF) * 2444900
6400                                     MSIV(M) = MSF
6410                             ELSE
6420                                     EHTNN = 0
6430                                     NSIV(M) = MSIV(M) +
MSP
6440                             END IF
6450                     ELSE
6460                             EHTNN = 0
6470                     END IF
6480             ELSE
6490                     IF STEMP(2, M) > 100 THEN
6500                             Q = (STEMP(2, M) - 100) * DX
* ROED * SPD
6510                             STEMP(2, M) = 100
6520                             MSP = Q / 2444900
6530                             IF (MSP + MSIV(M)) > MSF
THEN
6540                                     MLV = DEFF *
(MSIV(M) + MSP) / (DX * (M - 1)) ^ 2
6550                                     IF (MCDV(M) - MLV) <
MCDVF THEN
6560                                             MLV =
MCDV(M) - MCDVF
6570                                             ML = ML +
MLV
6580                                             MCDV(M) =
MCDVF
6590                                             OUTNODE =
OUTNODE + 1
6600                                             SCOM(1, M) =
FPCC
```

```
6610                        SCOM(2, M) = FOCC
6620                        SCOM(3, M) = FCCC
6630                        SCOM(4, M) = FFCC
6640                        SCOM(5, M) = FACC
6650                        SCOM(6, M) = FMCC
6660                        STEMP(2, M) = 100
6670                        EHTNN = (MSIV(M) + MSP - MLV - MSF) * 2444900
6680                        MO = MO - MOILADD
6690                        MSIV(M) = MSF
6700                    ELSE
6710                        ML = ML = MLV
6720                        PCMC = (MCDV(M) - (MSP + MSIV(M) - MSF)) / MCDV(M)
6730                        MCDV(M) = MCDV(M) - MLV
6740                        EHTNN = (MSP + MSIV(M) - MSF - MLV) * 2444900
6750                        MSIV(M) = MSF
6760                        CALL NEWCOMP(PCMC, SCOM(), M)
6770                    END IF
6780                ELSE
6790                    MSIV(M) = MSIV(M) = MSP
6800                END IF
6810            ELSE
6820                EHTNN = 0
6830            END IF
6840        END IF
6850    NEXT
6860    ROED = ROE(STEMP(1, NODE), SCOM(), NODE) * (1 - PAIR)
6870    KD = K(STEMP(1, NODE), SCOM(), NODE) * (1 - PAIR) * KEFF
6880    SPD = SPHEAT(STEMP(1, NODE), SCOM(), NODE) * (1 - PAIR)
6885    N = NODE - 1
6890    STEMP(2, NODE) = STEMP(1, NODE) + (KD / (DX * PCX)) * (STEMP(1, N) - STEMP(1, NODE)) / (DX * PCX * ROED * SPD)
6995    EHTNN = 0
6900    FOR N = 1 TO NODE
6910        STEMP(1, N) = STEMP(2, N)
6920    NEXT
```

```
6921     TPAN1 = TPAN1DT
6922     TPAN2 = TPAN2DT
6925     NEXT
6930     ML = ML * 3.141593 * (PANDIA / 2000) ^ 2
6940     IF ABS(NL - MLOSS) / MLOSS > .01 THEN
6950             DEFF = DEFF * MLOSS / ML
6960             PRINT "CALCULATED MOISTURE CONTENT:"; ML,
"CALCULATED FINAL TEMPERATURE:"; STEMP(1, NODE)
6970             GOTO 5050
6980     END IF
6990     IF ABS(STEMP(1, NODE) - TDSI) / TDSI > .01 THEN
7000             KEFF = TDSI / STEMP(1, NODE)
7010             GOTO 5050
7020     END IF
7030     CLS 2
7040     GOTO 99999
10000    CLS
10010    PRINT "PROGRAM NOT READY"
99999    PRINT "PROGRAM TERMINATED"


FUNCTION h (V, T, AIR(), D)
        X = 1
        DO UNTIL T <= AIR(X, 1)
                IF X = 10 THEN
                        X = 11
                        EXIT DO
                END IF
                X = X + 1
        LOOP
        IF X = 2 THEN
                X1 = 1
                X2 = 2
        ELSEIF X = 1 THEN
                X1 = 1
                X2 = 2
        ELSE
                X1 = X - 2
                X2 = X - 1
        END IF
        R = AIR(X2, 2) - (AIR(X2, 2) - AIR(X1, 2)) *
(AIR(X2, 1) - T) / (AIR(X2, 1) - AIR(X1, 1))
        MU = AIR(X2, 3) - (AIR(X2, 3) - AIR(X1, 3)) *
(AIR(X2, 1) - T) / (AIR(X2, 1) - AIR(X1, 1))
        KAIR = AIR(X2, 4) - (AIR(X2, 4) - AIR(X1, 4)) *
(AIR(X2, 1) - T) / (AIR(X2, 1) - AIR(X1, 1))
        NPR = AIR(X2, 5) - (AIR(X2, 5) - AIR(X1, 5)) *
(AIR(X2, 1) - T) / (AIR(X2, 1) - AIR(X1, 1))
        NRE = R * D * V / MU
        h = (KAIR / D) * .228 * (NRE ^ .731) * (NPR ^ .333)
END FUNCTION

FUNCTION K (T, SCOM(), N)
        P = .17881 + .0011958 * T - 2.7178E-06 * T ^ 2
```

```
        L = .18071 - 2.7604E-04 * T - 1.7749E-07 * T ^ 2
        C = .20141 + .0013874 * T - 4.3312E-06 * T ^ 2
        F = .18331 + .0012497 * T - 3.1683E-06 * T ^ 2
        A = .32962 + .0014011 * T - 2.9069E-06 * T ^ 2
        W = .57109 + .0017625 * T - 6.7036E-06 * T ^ 2
        K = P * SCOM(1, N) + L * SCOM(2, N) + C * SCOM(3, N)
+ F * SCOM(4, N) + A * SCOM(5, N) + W * SCOM(6, N)
END FUNCTION

SUB NEWCOMP (PCMC, SCOM(), N)
        NEW = SCOM(1, N) + SCOM(2, N) + SCOM(3, N) + SCOM(4,
N) + SCOM(5, N) + SCOM(6, N) * PCMC
        SCOM(1, N) = SCOM(1, N) / NEW
        SCOM(2, N) = SCOM(2, N) / NEW
        SCOM(3, N) = SCOM(3, N) / NEW
        SCOM(4, N) = SCOM(4, N) / NEW
        SCOM(5, N) = SCOM(5, N) / NEW
        SCOM(6, N) = SCOM(6, N) / NEW
END SUB

FUNCTION ROE (T, SCOM(), N)
        P = 1329.9 - .5184 * T
        L = 925.59 - .41757 * T
        C = 1599.1 - .31046 * T
        F = 1311.5 - .36589 * T
        A = 2423.8 - .28063 * T
        W = 997.18 + .0031439 * T - .0037575 * T ^ 2
        ROE = P * SCOM(1, N) + L * SCOM(2, N) + C * SCOM(3,
N) + F * SCOM(4, N) + A * SCOM(5, N) + W * SCOM(6, N)
END FUNCTION

FUNCTION SPHEAT (T, SCOM(), N)
        P = 2.0082 + .0012089 * T - 1.3129E-06 * T ^ 2
        L = 1.9842 + .0014733 * T - 4.8008E-06 * T ^ 2
        C = 1.5488 + .0019625 * T - 5.9399E-06 * T ^ 2
        F = 1.8459 + .0018306 * T - 4.6509E-06 * T ^ 2
        A = 1.0926 + .0018896 * T - 3.6817E-06 * T ^ 2
        W = 4.1289 - 9.0864E-05 * T + 5.4761E-06 * T ^ 2
        SPHEAT = 1000 * (P * SCOM(1, N) + L * SCOM(2, N) + C
* SCOM(3, N) + F * SCOM(4, N) + A * SCOM(5, N) + W * SCOM(6,
N))
END FUNCTION
```

Appendix 3: Program Notation

BOWT	oil weight after baking
BCTH	crust thickness after baking
BSPEED	belt speed
BSSWT	weight of baked shell and sauce
BSTH	shell thickness after baking
BWWT	weight of moisture absorbed from toppings by shell
COOKL	length traveled through at time t
COOKT	cooking time t
DEFF	effective diffusivity of crust
DX	thickness of each slice of dough
EHTNN	excess heat due to steam condensation passed to next dough slice
FACC	final percent ash in crust
FCCC	final percent carbohydrate in crust
FFCC	final percent fiber in crust
FMCC	final percent moisture in crust
FMOISC	final moisture in crust
FOCC	final percent fat in crust
FOILC	final fat in crust
FPCC	final percent protein in crust
IASHC	initial ash in crust
ICARBOC	initial carbohydrate in crust
IDASH	initial ash content of dough
IDCARBO	initial carbohydrate of dough

IDFAT	initial fat content of dough
IDFIBER	initial fiber content of dough
IDMOIS	initial moisture content of dough
IDPRO	initial protein content of dough
IFATC	initial fat in crust
IFIBERC	initial fiber in crust
IMOISC	initial moisture in crust
IPROC	initial protein in crust
ISASH	initial ash content of sauce
ISCARBO	initial carbohydrate of sauce
ISFAT	initial fat content of sauce
ISFIBER	initial fiber content of sauce
ISMOIS	initial moisture content of sauce
ISPRO	initial protein content of sauce
KD	thermal conductivity of dough
KEFF	correction factor for conductivity of dough
KOIL	thermal conductivity of oil
LENGTH	total length of the oven
M	counter
MCDV(N)	moisture in slice of dough at node N
MCDVF	moisture in slice of dough once it becomes crust
MCDVI	initial moisture content in a slice of dough
ML	total moisture loss at time t

MLOSS	total moisture loss during cooking
MLV	moisture lost from slice
MO	mass of oil in pan at time t
MOILADD	oil absorbed by crust in delta t
MSF	mass of steam that fills the voids in the a slice of dough
MSIV(N)	steam in void of dough slice N
N	counter
NEWMC	moisture in slice after delta t seconds of diffusion
NODE	number of nodes in shell
NOZONES	number of cooking zones in oven
OIL(1,1)	percent protein in oil
OIL(2,1)	percent fat in oil
OIL(3,1)	percent carbohydrate in oil
OIL(4,1)	percent fiber in oil
OIL(5,1)	percent ash in oil
OIL(6,1)	percent moisture in oil
OILD	oil density
OILT	oil temperature
OILTH	thickness of oil layer at time t
OUTNODE	number of ths slice of dough currently experiencing a moisture loss
P	pressure
PAIR	percent void space in dough
PANCON	pan thermal conductivity

PANDEN	pan density
PANDIA	pan diameter
PANEMIS	pan emissivity
PANSP	pan specific heat
PANTH	pan thickness
PBDTH	dough thickness before baking
PBDWT	dough weight before baking
PBOWT	oil weight before baking
PBSWT	sauce weight before baking
PCMV	percent moisture remaining in slice after delta t seconds of diffusion
PCX	initial dough thickness over final dough thickness
Q	heat
ROED	density of dough
ROW	variable used to determine user response
SCOM(1,N)	percent dough protein
SCOM(2,N)	percent dough fat
SCOM(3,N)	percent dough carbohydrate
SCOM(4,N)	percent dough fiber
SCOM(5,N)	percent dough ash
SCOM(6,N)	percent dough moisture
SELECT$	variable used to determine user response
SPD	specific heat of dough
SPOIL	specific heat of oil

STEMP(1,N)	dough temperature at time t
STEMP(2,N)	dough temperature at time t plus delta t
TCOOKT	total cooking time for pizza
TDSI	temperature of top of shell when cooking is complete
TPAN1	outside pan temperature at time t
TPAN2	inside pan temperature at time t
TPAN1DT	outside pan temperature at time t plus delta t
TPAN2DT	inside pan temperature at time t plus delta t
TPIN	temperature of pizza entering oven
VOLC	final volume of crust
VOLI	initial volume of dough
ZONEh	convective-heat transfer coefficient for cooking zone
ZONEH(N)	convective-heat transfer coefficient for oven zone N
ZONEL(N)	length of oven zone L
ZONES(N)	air speed in oven zone N
ZONET(N)	temperature of oven zone N