The Thermodynamics of a Turkey during Thanksgiving

Turkeys are native to North America, called "Indian fowls" in some writings of the 1500s. Around 1519, ships began transporting turkeys back to Spain, thus beginning its migration to Europe. American Benjamin Franklin advocated the turkey as the national bird.

The turkey became prominent in Europe in the 1800s during the holiday season, replacing the goose as the most popular Christmas bird in the latter part of the century.

In 1851, Queen Victoria had a turkey in place of her standard Christmas swan.

The Make-Up of a Turkey

At the biochemical level, a turkey is a combination of approximately 3 parts water to one part fat and one part protein. The majority of meat comes from muscle fibers in the turkey, which are mostly proteins—notably myosin and actin. Because turkeys rarely fly but rather walk, they contain far more fat in their legs than in their breast, which results in the strong differences in texture between these sections of the bird and the difficulty in making sure that all portions of the bird are properly heated.

The Science of Cooking a Turkey

As you cook the turkey, muscle fibers contract until they begin to break up at around 180 degrees Fahrenheit. Bonds within the molecules begin to break down, causing proteins to unravel, and the dense muscle meat to become more tender. Collagen in the bird (one of three protein fibers that attaches muscles to the bone) breaks down into softer gelatin molecules as it unwinds.

The dryness of a turkey is a result of muscle proteins coagulating within the meat, which can result if it is cooked too long.

Temperature Differentials

Part of the problem, as described above, is that the different nature of the light and dark meat in a turkey result in different rates to reach the coagulation of the muscle proteins.

If you cook it too long, the breast meat has coagulated; if you don't cook the bird long enough, the dark meat is still tough and chewy.

Harold McGee, a food science writer, indicates aiming for 155–160 degrees Fahrenheit in the breast, but you want 180 degrees or above in the leg.

Heating Differentials

Since you ultimately want the breast and legs to be different temperatures, the question is how to successfully accomplish this. McGree presents one option, by using ice packs to keep the breast of the bird about 20 degrees lower than the legs while thawing, so that the legs get a "heat start" on the cooking process when they're put in the oven.

Alton Brown, of Food Network's *Good Eats*, once presented another way to establish different heating rates, using aluminum foil to reflect heat away from the breast, thus resulting in the legs heating faster than the breast. His current roast turkey recipe on the Food Network website does not include this step, but if you watch the related videos, it shows the steps involved in using the aluminum foil.

Cooking Thermodynamics

Based on thermodynamics, it is possible to make some estimations of cooking time for a turkey.

Considering the following estimations, it becomes fairly straightforward:

- Assume the oven maintains a constant temperature throughout.
- Assume the thermal diffusivity is independent of temperature and time.
- Assume the turkey is so plump that it can be estimated as a sphere.

You can then apply the principles of Carlaw & Jaeger's 1947 *Conduction of Heat in Solids* to come up with an estimate for the cooking time. The "radius" of the hypothetical spherical turkey falls out, resulting in a formula based solely on mass.

Traditional Cooking Times

- Small bird - twenty minutes per pound + 20 minutes
- Large bird - fifteen minutes per pound + 15 minutes

It would appear that these traditional cooking times work well in conjunction with the thermodynamic calculations provided, which give the time as being proportional to the mass to the power of two-thirds.

Panofsky Turkey Constant

Pief Panofsky, former SLAC Director, derived an equation to attempt to more precisely determine the cooking time of a turkey. His problem is that he disliked the traditional suggestion of "30 minutes per pound," because "the time a turkey should be cooked is not a linear equation." He used t to represent the cooking time in hours and W as the weight of the stuffed turkey, in pounds, and determined the following equation for the amount of time the turkey should be cooked at 325 degrees Fahrenheit. According to the report, the constant value 1.5 was determined empirically. Here's the equation:

$t = W^{(2/3)}/1.5$

Particle Accelerators Create Shrink Wrap

The plastic shrink wrap that turkeys (specifically Butterball turkeys) come in may also have an amazing connection to particle physics. According to *Symmetry* magazine, some of these forms of shrink wrap are actually created by a particle accelerator. Particle accelerators use electron beams to knock hydrogen atoms off of the polymer chains within the polyethylene plastic, making it chemically active in just the right way so that when heat is applied it shrinks around the turkey. There's a bit more detail provided in the *Symmetry* article on the subject.