Sous Vide Cooking

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Introduction

Sous vide cooking has a few working definitions. The FDA Food Code (2013) uses "sous vide, in which raw or partially cooked food is placed in a hermetically sealed, impermeable bag, cooked in the bag, rapidly chilled, and refrigerated at temperatures that inhibit the growth of psychrotrophic pathogens." This reduced-oxygen-packaging sous vide processing can extend the shelf life of minimally processed foods. Since the 2000s, sous vide also describes any precise, temperature-controlled cooking in a water bath, especially for low-temperature and relatively long-time cooks for immediate service. Both sous vide for immediate service and for extended shelf life seek to maximize consistency and taste.

Restaurant and home cooks who cook sous vide often prefer it for meat, fish, and poultry over other methods. Suppose you want to cook a 30 mm-thick pork chop to 65 °C for a medium doneness. Using traditional methods, you might do the following to cook the pork chop: heat some butter and oil to 140 to 160 °C in a skillet; add the pork chop and flip it every few minutes while spooning hot butter and oil over it; when the core reaches 62 °C, you remove the chop and let it rest while the residual heat brings the core to around 65 °C. With sous vide cooking, you might do the following: place the chop in an impermeable, food-safe bag with some oil; put the bagged chop in a 65 °C water bath for about an hour — you can hold it for many additional hours without affecting safety, texture, or appearance; remove it from the bag and pat it dry with paper towels; quickly sear it in a 200 to 300 °C cast-iron skillet for 20 seconds on each side. While faster, the traditional method requires your attention and careful timing to keep the pork chop from being under- or overcooked and skill to keep the surface from burning before it's cooked through. Sous vide cooking, by separating the cooking and the searing, gives much greater consistency and control over texture, safety, and appearance with no worries about overcooking.

First, select foods that benefit from precise temperature control at temperatures below the local boiling point. Chefs often cook fish at 35 to 55 °C, tender meat and poultry at 50 to 65 °C, tough meat at 55 to 95 °C, starchy vegetables at 75 to 90 °C, other vegetables at 80 to 95 °C, and beans and legumes at 90 to 95 °C. Use bath temperatures over 75 to 80 °C to extend shelf-life or create a braised texture. While industrial processors cook beans and grains sous vide, restaurant and home kitchens mainly use sous vide cooking for meat, fish, and poultry. Tender cuts, such as tenderloin, are usually just heated through and then browned with high heat for flavor and appearance. Other tender cuts, like chicken breasts, are cooked and pasteurized. For tough cuts, such as beef short ribs, a long time at a low temperature, say two to three days at

58 °C, gives a tender, steak-like texture; while a shorter time at a higher temperature, say 12 to 24 hours at 85 °C, gives a succulent, braised texture.

Whether to pasteurize or not depends on the hazard posed by the raw food and the risk to the individuals being served. For example, consider the hazards associated with a seared boneless steak with intact muscle: with proper handling, it has no physical, chemical, or microbiological hazards for a healthy adult because intact muscle is effectively sterile inside and searing destroys surface microorganisms. Compare this with ground poultry: grinding spreads surface microorganisms throughout, posing a microbiological hazard, and bone fragments pose a physical hazard. But both would need pasteurizing if serving a high-risk, immunocompromised individual because of the high risk posed by even a few active food pathogens. Cooking for extended shelf life also requires pasteurization: pasteurized food in a hermetically sealed bag, can be rapidly cooled and refrigerated for 30 days below 3 °C or frozen indefinitely.

After cooking sous vide, meats are often finished with high heat to produce the Maillard reaction for flavor and appearance. This is often done with a hot pan or grill or under a broiler for a short time to minimize overcooking.

Packaging

Most sous vide cooking is done in food-safe plastic bags. Separating the food from the water has several benefits: Cooking in a bag reduces nutrients and flavor leaching from the food into the water. Removing most the air improves heat transfer from the water to the food because air is a good insulator and too much air causes bags to float and the food to cook unevenly. Cooking in a hermetically sealed bag prevents recontamination after pasteurizing. Pulling a vacuum before sealing — 'sous vide' meaning 'under vacuum' in French — can reduce fat oxidation, warmed-over flavors in pre-cooked meat, and microbial growth.

In larger kitchens, the food is sealed in multi-layer hermetically sealed bags using a chamber vacuum sealer. For a chamber vacuum sealer, the food is put in a bag, the bag is placed in a chamber with one edge over a seal-bar, then most of the air is removed from the chamber, the seal-bar uses heat to hermetically seal the bag, and then air is allowed to reenter the chamber. In smaller kitchens without a chamber vacuum sealer, there are a variety of options for cooks wanting to sous vide, especially if extended shelf life is not important. Zipper-topped food-storage bags designed for reheating food, such as being microwavable, are also suitable for sous vide cooking for immediate service: put the food in bag, then quickly dunk the bag in the water with the top open and above the water to displace most of the air, then seal the bag and submerge completely under the water. (For short cooks that don't require pasteurization, it can be convenient to clip the bag on the side of the container, but the whole bag should be submerged when pasteurizing since food pathogens might have been smeared on the bag's inside surface that is above the water level.) Since these zipper-topped bags sometimes leak or have seams that fail, a multi-layer textured bag sealed with a clamp-style vacuum sealer is more robust; when sealing food with liquid in the bag, it's important to stop the vacuum and seal the bag before the liquid reaches the seal-bar and the vacuum pump, it helps to have the vacuum sealer above the food. When cooking for immediate service, reusable silicone bags designed for food storage and cooking can be used; when using reusable bags, it's important to thoroughly clean them and to separate those used for people with food allergies. Jars are also used for foods like jarred eggs, custards, and cheesecakes.

What is in the bag with the raw meat, fish, or poultry can affect how it cooks. For example, adding dry salt or a concentrated salt brine will draw water out of the flesh, while a less concentrated brine can draw water into the flesh, and all these mass transfers occur more rapidly as the temperature increases. An acidic marinade will result in less water loss compared with cooking in a bag without additional ingredients, with oil, or with a brine at a similar salt concentration as the food, which all have similar water losses. Cooking in a sauce or with strongly flavored ingredients can enhance the meat. Often cooking in sauce precludes post-cook searing, and the sauce should be thickened so lost juices don't make it too thin. For herbs and spices, vacuum sealing them without a liquid in the bag will press them unattractively against the food. And adding sufficient oil, brine, or stock to allow movement usually improves the appearance of meat, fish, poultry, and vegetables: if the food can't move within the bag, the edges often look crimped from the bag; oils and sauces often prevent albumin, water-soluble proteins that denature and coagulate, from coagulating on the surface. In general, small molecules, like some volatile flavor compounds, salts, and sugars, can diffuse into muscle, while larger molecules, like fats, cannot.

Cooking sous vide

In restaurant and home kitchens, most often an immersion circulator precisely controls the water temperature that the packaged food cooks in. Unlike most heat sources in the kitchen, some immersion circulators can keep the water's temperature to within ±0.1 °C of a setpoint. For meat, fish, and poultry, temperature control within ±0.5 °C is sufficient between about 35 and 70 °C and ±1.0 °C above about 75 °C. While less precise cooking can produce noticeable differences, animal-to-animal variation masks differences from more precise cooking. Sous vide cooking is also done in convection steam ovens, water ovens without forced convection, and on stovetops. For steam ovens, the air needs to be saturated with water to cook efficiently; this is difficult to achieve outside 65 to 90 °C. Water ovens and uncirculated water baths have a lower heat transfer coefficient than forced convection (see Chapter **000** on heat transfer in culinary science), but it's high enough that recipes usually do not need adjustment; the popularity of immersion circulators over water ovens mainly comes from the circulator's compact size and its flexibility to use multiple bath sizes. Stovetop sous vide is best done with a large pot, a relatively short cooking time, a good thermocouple or thermistor thermometer, and a lot of patience from whomever is adjusting the burner's dial. For cooking times longer than a few hours or water temperatures over about 70 °C, consider covering the bath to reduce evaporation.

Meat, poultry, and fish

It is convenient to divide meat, fish, and poultry into tender and tough cuts: Tender cuts just need heating through for acceptable appearance and texture, and are sometimes held longer to pasteurize them for safety. Tough cuts, usually from large, powerful muscles, benefit from longer cooking times or higher temperatures to transform them so they are acceptably tender.

Doneness, appearance, and texture

Meat is about 75% water, 20% protein, and 5% fat and other substances. When cooking, some of these proteins denature; which proteins have denatured determine the doneness. It's helpful to divide the proteins into muscle fibers, soluble proteins, and connective tissue — see Tornberg (2005) and Chapter **000** on heat transfer in meat for how these proteins change with temperature.

The soluble proteins mostly determine the appearance, especially for red meat. When they start to denature and scatter light, the muscle goes from translucent to opaque and reds become pinker and whites whiter. At higher temperatures the soluble red or purple myoglobin denature to brown, unless cured with nitrate or nitrite so the myoglobin is a stable pink color.

The texture mainly depends on the muscle and what temperature it's heated to and for how long. Large, powerful muscles have more fat and connective tissue than smaller, weaker muscles. With higher cooking temperatures and longer cooking times, this fat melts and the connective-tissue collagen dissolves into gelatin; this gelatin and fat lets the muscle fibers easily slide against each other when chewing, along with saliva, and makes tough cuts succulent. Tender cuts, without this abundant fat and connective tissue, do not become succulent at higher temperatures; they become dry and stringy because muscle fibers and collagen shrink and squeeze out water and denatured soluble proteins gel and trap water. But at lower temperatures, tender cuts are juicy because biting into them gives a burst of moisture.

Tender cuts

Since tender cuts just need heating through, it's helpful to understand how they heat; cf. Chapter **000** on heat transfer in meat. In general, the rate of heat transfer is proportional to the difference in temperatures. So this gives two heat transfer rates to estimate: how heat gets from the water to the food's surface and how it gets from the food's surface to its core. In many foods, you can assume that either the food is a uniform temperature or the surface temperature equals the fluid temperature. But in sous vide cooking, both these effects are important; so it takes sophisticated mathematical modeling to determine when the food will be perfectly cooked.

Most sous vide cooking is so-called equilibrium cooking, where the water bath is set to just above the meat's desired core temperature. The core cannot exceed the water bath's temperature, so in that sense the food can never overcook. So while a 25 mm steak cooked in 55 °C water is ready in about an hour, it can be held for an additional two to three hours without a noticeable difference in color or texture. Since the heat-transfer rate is proportional to the difference between the water's and food's temperatures, heating the core from 50 to 54 °C takes longer than it took to heat from 5 to 50 °C. So restaurants often use so-called high-ΔT sous vide cooking to reduce the heating time: rather than cook a 25 mm steak to 54 °C in a 55 °C water bath, they might use a 65 °C water bath and use a thermometer to remove it when the core reaches 53 °C after 15–20 minutes. This high-ΔT sous vide cooking cuts heating time, but removes the ability to hold the food in the water bath without overcooking it.

Tough cuts

The changes in water-soluble proteins and connective tissue depend on both time and temperature. While the changes happen quickly at a higher temperature, they occur more slowly at lower temperatures. Above 53 to 55 °C, where food pathogens stop growing, the holding time needed for such changes halves every 5 to 10 °C increase in temperature. But they don't all change with the same rate as the temperature changes, so you might cook beef shank at 80 °C for 16 hours for a braise-like texture or at 60 °C for 48 hours for a steak-like texture.

Traditionally, tough cuts like pork shoulder and beef brisket are smoked for long periods at relatively low temperatures to transform their connective tissue and fat to make them fork-tender; similarly, braising transforms tough cuts in pot roast, goulash, and so on into tender and succulent feasts. Compared with rib and back muscles, these leg, shoulder, butt, and neck muscles are strong and powerful in four-legged animals. The same muscles in different animals require similar time-and-temperature combinations; beef, sheep, pig, deer, and buffalo shoulders have a steak-like texture after 24 hours at 55 to 60 °C and a braised texture after 12 hours at 80 to 85 °C.

Storing and reheating

Sous vide cooking for extended shelf-life involves rapidly cooling the cooked food and then either refrigerating it at low enough temperatures to inhibit pathogen growth or freezing it. The temperature required to inhibit food pathogen growth depends on what and how it was cooked. Let's consider spoilage microorganisms, pathogenic microorganisms, and spore-forming bacteria. Some spoilage microorganisms are true psychrophiles and can grow in most freezers, but cooking usually destroys them. Other microorganisms, like *Listeria monocytogenes* and *Yersinia enterocolitica* can grow slowly at refrigerator temperatures below 5 °C if not destroyed during cooking. Other bacteria like *Clostridium botulinum*, *Clostridium perfringens*, and *Bacillus cereus* can form spores that aren't destroyed when pasteurizing for active (vegetative) pathogens; the spores can germinate and grow if cooled too slowly or stored for too long. See Chapter **000** on microbiology and Jay's *Modern Food Microbiology* (7th ed., 2005) for more on food microbiology.

Let's consider three example recipes to illustrate these cases:
Salmon filet heated to 40 °C for 60 minutes: While 40 °C is too low to pasteurize the salmon, a salt and sugar cure can enhance taste, texture, and safety: the cure makes it harder for cold-growing food pathogens to grow. Soak a skinned and trimmed salmon loin in a cold 10% salt, 5% sugar brine for 45 minutes. Then remove from the brine and pat dry with a paper towel before vacuum sealing and cooking at 40 °C for 60 minutes. Then rapidly chill the salmon still in the bag in ice water before refrigerating for up to a week and serving cold. Without the salt-and-sugar cure, limiting *Yersinia enterocolitica* growth would give a maximum storage time of just one day. For recipes that combine several hurdles, or partial but not complete controls for biological hazards, challenge tests are often necessary to demonstrate acceptable risks.
Chicken breast cooked at 65 °C for 1 hour: This will pasteurize a typical boneless, skinless chicken breast for *Listeria monocytogenes*, and will also destroy other vegetative food pathogens. But it will not destroy the spore form of some foodborne bacteria. So storing below 3 °C, the minimum temperature for *C. botulinum* growth, gives a 30 day shelf-life, though regulations vary.
Beef short ribs cooked at 70 °C for 24 hours: The time required to get the desired texture at 70 °C exceeds the time required to destroy non-proteolytic *C. botulinum* spores, the types of *C. botulinum* that can germinate and grow below 10 °C. But this gives little practical increase in shelf life because the minimum growth temperature for *Bacillus cereus* is 4 °C. To have significantly longer shelf lives requires more than just sous vide cooking: you would need hurdles similar to those used in canning (such as a pH below 4.6, enough salt or sugar to reduce water activity below 0.91, or pressure cooking to destroy all spores), fermentation, or curing.

Finishing for service

While some food is ready to serve immediately after cooking sous vide, others benefit from searing because the browning or Maillard reaction adds savory and roast flavors. Searing or grill-marking meat, poultry, and fish, especially when cooked with a sauce in the bag, does not need searing again after cooking for flavor or appearance. Food with delicate flavors that searing would overwhelm, such as skinless finfish, skinless poultry, shellfish, vegetables, and fruit, are also ready for service right from the bag.

Searing in the shortest practical time has several benefits: it limits overcooking already cooked food and may reduce mutagen formation. While mutagens formed in the Maillard reaction may not be carcinogenic in humans, reducing their formation reduces risk. Over about 150 °C, the reaction rate for forming mutagens doubles about every 25 °C; the amount increases almost linearly in time before leveling off after 5–10 minutes; so using high temperatures for just 5 to 30 seconds is unlikely to cause significant mutagen formation. We can estimate the depth of overcooking using meat's thermal diffusivity of between 0.1 to 0.2 mm²/s: in 5 to 30 seconds the heat diffuses $\sqrt{(5\,s)(0.1\,mm^2/s)} \approx 0.7\,mm$ to $\sqrt{(30\,s)(0.2\,mm^2/s)} \approx 2.4\,mm$. So searing for a short time at a high temperature maintains sous vide cooking's characteristic edge-to-edge doneness. For example, many cooks will dry a steak with paper towels, lightly coat the steak with oil and season with salt and pepper, then heat a heavy cast-iron pan to 200 to 250 °C and sear it for 10 to 20 seconds on each side until the beef is a rich mahogany brown. Other cooks use a blow torch, a gas or charcoal grill or even a grate on a chimney charcoal starter, a salamander or broiler, or a deep-fat fryer — the best method depends mostly on the recipe's goal.

References and further reading

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