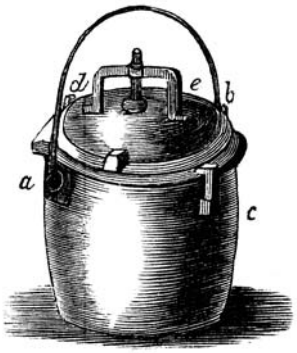
Cooking Under Pressure: Applying the Ideal Gas Law in the Kitchen



by

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In this story, concepts such as vapor and external pressures, boiling point, the ideal gas law, and chemical reaction rates are emphasized.

It is 6 p.m. and the Clarksons are preparing dinner for their friends, Carol and Steve. Ben is a truck driver and has been taking some night classes at a local community college for enrichment. Ann also leads a busy life, working two jobs. She has decided that tonight, in the interest of time, to try out the new pressure cooker she recently received for her birthday.

Ann: Honey, our guests are going to be here soon! Will you taste the beef stew? Let me know what you think so I can whip up a dessert quickly.

Ben: Yes, boss. Hmm … definitely under-cooked. Carol and Steve won't like that.

Ann: What? How come? The pressure cooker should cook food faster.

Ben: Did you forget to use the vent stopper?

Ann: Shoot, I sure did. What does it do anyway?

Ben: Do you really want to know? I just learned about the gas laws in my chem class, very interesting stuff.

Ann: Sure, tell me more about it.

Ben: All right. As you know, water normally boils at 100°C, so the temperature of water can't exceed 100°C in an open vessel (like what's used in conventional cooking). Under normal conditions (1 atomsphere external pressure at sea level), any food in water can't be cooked at temperatures greater than 100°C. However, the boiling point of water varies with external pressures—water boils at a higher temperature when the external pressure is increased. So the higher pressure inside a pressure cooker lets the water boil at temperatures greater than 100°C. Make sense?

Ann: So when the external pressure is lowered, water boils at a lower temperature?

Ben: Exactly! Pressure cookers are designed to cook foods at higher temperatures so the cooking gets done faster!

Ann: Okay, what's the vent stopper have to do with the temperature?

Ben: All right. A pressure cooker consists of a pot and lid, which are usually made of metals such as aluminum or stainless steel. The lid has a rubber ring to seal off the space between the lid and the pot, a safety valve made of low melting point alloy, a vent to allow steam to escape, and a detachable vent stopper or pressure regulator that sits on top of the vent throughout the cooking process. This pressure regulator generates extra force (pressure) in addition to the atomspheric pressure (1 atm), which allows water inside the pot to boil under a higher pressure and hence at a temperature higher than its normal boiling point (100°C). So, food can be cooked at a higher temperature (usually 125°C for most pressure cookers). According to my chem teacher, generally, for every 10°C increase, chemical reaction

rate doubles. However, without the stopper, such as in your case, since there was no extra external pressure, your beef stew was cooked at regular speed at 100°C.

Ann: I see. What are some of the other advantages of using a pressure cooker besides saving time?

Ben: Well, you use less fuel, and there's better retention of certain nutrients due to less water required and shortened cooking time (up to 70% faster than with conventional cookers). In addition, toxins and mircobes can be destroyed more efficiently at greater temperatures. The same logic applies to canning foods and autoclaving instruments.

Ann: Why have safety valves?

Ben: Well, if the vent is clogged with food, no steam can escape from the pot. Under such circumstances—a sealed and rigid container—continuous heating would cause the steam pressure to build up inside the pot, which can be very dangerous and may cause an explosion.

Ann: That's not good.

Ben: Nope, it's not. This can be explained by the ideal gas law: $PV = nRT$, meaning when volume *(V)* and temperature *(T)* are constant, more gas particles (*n,* numbers of moles of gas: mole is a counting unit used by chemists) generate higher pressure *(P); R* is a constant, i.e., ideal gas constant. The safety valve is used to prevent such dangerous conditions.

Ann: Wait, I know volume is constant since the cooker is made of metals. But did you say *T* is also constant?

Ben: Yes. At the beginning of boiling, although heat is constantly absorbed by water, it is used to convert liquid to gas, a physical state change; therefore the water temperature remains constant.

Ann: I see. And how does the safety valve work?

Ben: After the vent is clogged up, the higher pressure, generated by the accumulated steam, in turn raises the boiling temperature, and both the water and steam get even hotter. Once the temperature inside the pot reaches the melting point of the valve, the valve melts right away in order to release the steam (*n* decreases) and the pressure (*P* decreases as well), thus preventing explosions. Some pressure cookers come with a small basket or guard underneath the vent to prevent any clogging from food.

Ann: Gotcha. Oh, I smell the aroma of the stew. Just in time!

Questions

1. How does external pressure influence the boiling point of water?
2. How does a pressure cooker speed up the cooking?
3. According to Chef Robert Sevaly, pressure cookers "really are a timesaver, cutting your cooking time by three-fourths." If a person spends an average of 10 hours cooking per week, how much cooking time would be saved in a month and a year, respectively? (Assume pressure cookers are used in preparing every meal.)
4. If an average household spends $20 in natural gas for cooking per month, how much money would be saved by using a pressure cooker in one year?

5. At a higher altitude (e.g., Mount Everest), why does it take longer to cook?
6. Would a pressure cooker come in handy at Mt. Everest? Explain.
7. Why does a slow cooker cook slowly?
8. What are some other benefits of pressure cooking (other than saving time)?
9. Can you use a pressure cooker to cook dry food, such as breads or pancakes? Explain.
10. What is the air pressure inside the pot after the safety valve melts? Explain.
11. What is the advantage of using an autoclave (generates steam with high pressure and temperature) to sterilize surgical instruments rather than simply boiling them in water?
12. Why is induced hypothermia used for patients who are undergoing certain surgeries?
13. During the boiling process, although energy is continuously provided, the temperature of the water is constant. Explain where the energy goes.
14. Calculate the pressure, in mmHg, of 20.0 g oxygen gas, in a 50.0 L container at 25°C. (The value of *R* is 0.0821 L·atm/mol·K.)
15. A humidifier can be a burn hazard. Why does 100°C steam burn more severely than 100°C of water?

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