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Abstract

The aim of this investigation was to come up with a technique for cooking the perfect steak in the context of slapping a steak onto an Aussie BBQ, consisting of just a hot plate with no added oils or herbs. The subject of countless arguments, this study seeks to use high level scientific monitoring techniques to measure the uniformity of the cooking process and to come up, once and for all, with the best way of cooking a perfect steak.

36 individual steaks sliced to a thickness of 20mm from the same cut of rump were sourced from a butcher. The first experiment with 18 steaks, organised into triplicates, had the flip rate as the independent variable with rates of 15s, 30s, 1min, 2min, 4min and no flip for steaks cooked for equal 8 minute periods. A Data Harvest temperature probe inserted laterally into the centre of the steak continually logged the internal temperature of each cooking steak while a FLIR Thermal Imaging Camera measured the upper surface temperature before and after each flip. A flip rate of 1min was found to give the most uniform cooking of the meat.

A qualitative study of the spectral distribution of the pixel colours were analysed using a spectral frequency histogram for Experiment 2. Steaks cooked for 4min, 6min and 8min each flipped every minute were then sliced once every minute during the resting phase to see if the steaks browned while resting. The steak cooked for 6 minutes continued to cook the most while in this resting phase.

The final experiment with 12 steaks organised into duplicates, sought to measure the mass of the juices that were released during the resting phase for steaks cooked for 2min, 4min, 6min, 8min, 10min and 12min, with each steak being flipped every minute. Again the steak cooked for 6 minutes released the most juices and maintained its core temperature for a few minutes during this stage.

No matter if you prefer rare, medium rare, medium or well done, the ideal flipping rate is once every minute and the juiciest and best looking steak is a medium rare steak cooked for 6 minutes and allowed to rest for 3 minutes. These rates obviously change according to the thickness and type of steak, however, for the typical steak of mass 180-200g, slapped on an Aussie BBQ these are the ideal techniques for cooking a perfect steak, using real science! Enjoy and try it out!
Introduction

How do you cook the best steak? This is a universal question that everyone has their own answer to. Jamie Oliver (2016) prefers to cook his steak in olive oil for 6 minutes, turning the steak every minute. Gordon Ramsay (2014) prefers to season his steak and cook it for 5-6 minutes, turning the steak every minute. Heston Blumenthal (2013) prefers to cook his perfect steak for 4 minutes, turning it every 15-20 seconds. All these food experts use pre-heated small fry pans with oil and spices to enhance the flavours. What about the average you and I, cooking a steak on an Aussie BBQ without the bells and whistles? When is it best to flip the steak? How long do you leave the steak on the BBQ? How long do you let it rest after cooking? These are all questions that I am planning to answer in this investigation using real science.

My interest in cooking steaks and cooking meat in general comes from a life-time of observing my parents running three kebab shops and working half my life alongside them. Family get-togethers around the barbeque are common place and so are arguments whether the steaks should be flipped or not flipped. It is the purpose of this research project to answer, once and for all, the best procedure for cooking a steak on an Aussie BBQ.

Aim

When cooking a steak on an Aussie BBQ, without using additives such as oils and spices, what is the best rate of flipping a steak and how long should the steak be cooked for? Are there any other techniques that should be employed to obtain the perfect steak?
**Background Research**

In cooking a perfect steak, there are a vast number of chemical and physical factors that need to be considered. Such factors include:
- the chemical composition of meat and how meat responds to heat
- meat flavour and heat
- the thermodynamics of heat transfer from the hotplate through the steak
- the effect of flipping a steak on uniformity of heat transfer
- taking food science into the realm of real science

**Chemical Composition of Meat and How Meat Responds to Heat**

Meat chemical composition contains 56-72% water, 15-22% protein, 5-34% fat, 3.5% soluble non-protein substances (including salt (organic), carbohydrates, dissolved nitrogen compounds, minerals and vitamins). Meat is mostly made up of water, protein and fat. Carbohydrates, minerals and vitamins are present in smaller amounts. When meat is heated up, the strong collagen connective tissue will weaken and soften into a gel, then harden as the meat is cooked for longer.

Raw meat should be cooked to a safe minimum internal temperature. To measure this, a meat thermometer can be used, so when it reaches the minimum internal temperature you can be notified. After the meat is cooked, it can be rested for up to 3 minutes to allow for increased texture quality. When meat is heated the fat and collagen melts, meaning the meat fibre shrinks and gets harder, but then it will ease when the temperature goes below the boiling point of water. It is important to understand that meat is a muscle, and has a structure to it that is changed by heating.

![Figure 1 - Structure of meat fibres](http://blog2.thermoworks.com/2017/02/coming-heat-effects-muscle-fibers-meat/)

Meat is cooked for these good reasons:
1. To make the meat safe to eat;
2. To make the meat easy to digest;
3. To make the meat more flavoursome;
4. To make sure the meat is easy to chew.
When cooking meat there are many physical changes caused by the heating meat. The once soft and squishy feeling meat can change to a tough or tender piece of meat; the meat can shrink; the meat changes from a red colour into a brown colour and the more the meat cooks, the less juice there is; the once translucent substance becomes opaque. Myoglobin is the reason why meat is red, and once the myoglobin is heated it changes into a brown colour, and this change occurs at 60 °C. This transition is visible in the image below:

![Figure 2](http://www.neogaf.com/forum/showthread.php?t=1400757&page=6)

In Figure 2 we can tell the different types of steaks, depending on their colour. The more the steak cooks, the more it becomes “well-done”. If the steak is just red and hardly cooked then it is “blue”, which means only the surface is cooked. This is the minimum, where the centre of the meat is least cooked. When the muscle fibres have physical damage, such as heat, the muscle fibres let out more of their fluids. When a steak is cooked for longer, there will be less juice remaining in the steak. The meat starts to shrink, because the meat is losing moisture and there are changes in the protein fibres.

**Meat Flavour and Heat**

When meat is raw it has less flavour. By cooking meat, the flavour of the meat increases and this creates its distinct smell. When the meats temperature increases, the meat will dry out, and physical changes will occur. Distinct flavour compounds will develop as organic molecules combine with each other, forming complex flavour molecules. These new molecules do not only smell like meat, but may also have other flavour characteristics. You can determine the flavour of meat by the breakdown of products, such as fats and proteins. This occurs when the meat is hotter than the boiling point of water. When you fry, grill or roast meat the crust of the meat generally is more flavoured. This is because as the meat dries out and it increases temperature, Maillard browning reactions occur that develop flavour compounds.
The Thermodynamics of Heat Transfer from The Hotplate Through the Steak

When cooking steak there is a heating element (the gas outlets), a heat transfer medium (BBQ hotplate), and the food that is being cooked. These factors all affect the rate of heat transfer.

Conduction transfers the heat to the steak by direct contact with the heat transfer medium. As the surface of the meat increases in temperature, heat is transferred through the steak to its interior by the water and fat contained in its cells. This transfer of thermal energy causes physical changes in the meat’s structure at the molecular level. Firstly, the protein myosin begins to coagulate at 50ºC. In an uncooked steak, there is water trapped within and between the protein fibres of the meat.

As the myosin molecules bond, they squeeze out the liquid that had been between them. This escapes a little out the sides of a steak, but mostly out the top and bottom of the steak, where the fibres are cut and exposed. Next, at around 60ºC other proteins begin to coagulate causing the meat to change into a more consistent structure as it gains firmness and continues to release moisture. As the temperature rises from 60ºC to 65ºC, collagen is denatured which shrinks the muscular sheathes around the meat fibres, causing the meat to release juice rapidly until it is dry, shrunken and chewy. The steak can lose up to 1/6th of its volume in this stage. If the cooking process is continued, collagen completely dissolves into gelatin and causes the meat fibres to fall apart, giving the apparent texture of tenderness.

The ideal cooking method would take these changes in the physical chemistry of the steak into consideration when cooking. The renowned food writer Harold McGee states that steaks should be “heated rapidly and just to the point that their juices are in full flow.” The aim is to achieve a particular internal temperature that ensures that the centre of the steak is cooked to the desired texture.

The Effect of Flipping a Steak on Uniformity of Heat Transfer

When a steak is cooked, the surface that is being cooked and facing upwards will start inhibiting brownness. This is because when flipping a steak, the more the steak gets flipped there is a more effective evaporation of moisture on the surface. McGee states that, flipping a
steak multiple times cooks the steak 30 per cent faster than flipping the steak once. He advocates flipping a steak every 30 seconds and ignoring all the traditional outdoor BBQ “experts” who say that you need to leave a steak to cook in its own juices and recommend only flipping a steak once.

By flipping a steak multiple times the two surfaces are being exposed to heat evenly, and with very little time to cool down before it gets flipped again. Therefore, flipping the steak during cooking has two advantages: it cooks faster, and it cooks evenly, according to Howard McGee. When flipping the steak both sides are equal, even the edges cook evenly.

![Figure 4](http://www.seriouseats.com/2013/07/the-food-lab-flip-your-steaks-and-burgers-multiple-times-for-better-results.html)

Figure 4 demonstrates a steak flipped multiple times and a steak that is flipped once. The steak on the right has been flipped multiple times, and this can be seen by the even colouring on the edges. The steak on the left has been flipped once because there is a grey band and, and then a pink in the middle; telling us the steak has not been cooked evenly. Flipping your steak multiple times has advantages such as, better taste, juicier and even cooking. Every source, or article that has been looked at has different opinions.

Taking Food Science into the Realm of Real Science

The unique feature of this investigation is that it involves advanced instrumentation to physically measure the uniformity of heat transfer involved in the cooking process. All literature relating to cooking the perfect steak use qualitative observations of colour, texture and taste to determine whether a steak is cooked uniformly. The scientific apparatus is limited to a meat thermometer that is inserted into the centre of a steak once or twice to determine if the steak is ready to be removed from the heat source.

Every expert has their preferred flipping rate and cooking times and it is hard to argue which method is the best for there is no analytical evidence for comparison. The ultimate analytical tool would be to have a 3D thermal camera that is able to measure the internal temperature of every millimetre of meat fibre in all three dimensions and use high powered computers to build 3D images of a steak while it is cooking, to work out which cooking process produces the most uniformly cooked steak. Unfortunately such technology has not yet been invented as thermal cameras purely record the intensity of infrared radiation emitted from the surface of an object.

The second-best option, which has been implemented in this study is to use a thermal imaging camera to measure the top surface temperature of a steak (see Figure 5) and a temperature sensor inserted into the centre of the steak which continually logs the core internal temperature. In this experiment this was achieved by using a FLIR C2 Thermal Imaging camera borrowed from FLIR Systems Australia and a Data Harvest temperature Sensor sourced from my school laboratory. In tandem these thermal data points were used to more accurately measure the heat transfer in each steak during the varying cooking processes.
Figure 5 - Visual image and thermal image taken concurrently of Steak 2 at the 3 minute mark. Notice that foil is wrapped around the temperature sensor to protect it from the hotplate.

To accurately measure the uniformity of colour in a piece of cooked meat, this study utilised the spectral analysis feature attached to Corel Photo Paint. This tool looks at the colour of each pixel in a selected area and gives a statistical analysis of the variation in the colours. Obviously the lower the standard deviation the more consistent the colour and hence the more consistent the cooking process. I will just be using the red channel to measure the change in redness of a steak as it is cooked.

Figure 6 – Spectral analysis of lateral cross-section of Steak 2 after cooking for 8 minutes, having being flipped every 15 seconds.

Hypothesis

On an Aussie BBQ, without all the bells and whistles, my hypothesis for cooking the perfect steak is to flip the steak every 30 seconds as Harold McGee suggests. It will provide a mechanism for effective heat transfer without allowing a side to cool down when away from the heat source for too long.
Experimental Regime

What was going to be a single large experiment cooking 36 similar steaks in triplicates at flipping rates ranging from 5 seconds, 10 seconds ... through to 8 minutes ended up being a series of experiments that built on the results of the previous experiment, exploring the qualitative and quantitative dynamics of the meat as it was cooking and then relaxing in the “resting phase”.

Experiment 1

Experimental Sample

In Experiment 1, the lightest 18 steaks were used that ranged in mass from 164g to 184g. To increase the reliability and validity of the experiment these were organised in triplicates so they had an average mass ranging from 175.27g to 176.11g. Statistically these six sets of triplicate steaks had a mean of 175.66g with a standard deviation of 0.31g.

Validity, Accuracy and Reliability

All 18 steaks were cooked on the same position of a barbecue plate for 8 minutes each, with the same heat settings on the same day and the plate was cleaned with a paper towel between each steak. The only variable that was changed (independent variable) was the time interval between when each steak was flipped. A stop watch was used to ensure accurate timing and an electronic balance was used to measure the mass of each steak. The data logger temperature sensor has a listed resolution of ± 0.1°C and the Flir C2 Thermal Imaging Camera had a listed thermal sensitivity of < 0.1°C.

For the first round of 6 steaks the first steak was cooked for 8 minutes without flipping. The second steak was cooked for 8 minutes and flipped once at the 4 minute mark. The subsequent steaks were flipped every 2 minutes, then 1 minute, then 30 seconds with the sixth steak being flipped every 15 seconds. At the end of 8 minutes each steak was taken off the hot plate and rested by itself in an aluminium tray for 2 minutes. A Data Harvest data logger with a temperature sensor measured the internal temperature of each steak for the full duration of each trial and a Flir C2 Thermal Imaging Camera measured the surface temperature of each steak before and after each flip. The whole experiment was repeated twice to increase the reliability of the results.

Also at the conclusion of each of the 18 trials, the steaks were cut in half and a photo was taken of the lateral cross-section. Using a spectral histogram feature on Corel Photo Paint, the uniformity of the red pixel was analysed to determine the eveness of the cooking process.

Need for further exploration

Although Experiment 1, clearly demonstrated that uniform cooking is best achieved when the steak is flipped every minute (slightly different from what I hypothesised), there was one particular observation that just staggered me and led me to run the two further experiments. It was noticed that the internal temperature of each steak actually increased when it was taken off the hot plate and placed in the aluminium tray. I did not know at first how this was thermodynamically possible but after further research I found that the tissue cells in the meat relax when removed from the heat, allowing the juices from the cells to be released thus providing a medium for heat transfer in the centre of the steak. This “resting phase” is well known by chefs as a vital stage in the cooking of a perfect steak and it was this “resting phase” that was further explored in Experiments 2 and 3.
Experiment 2

Experimental Sample

Experiment 2 was a qualitative study examining the browning of steaks during this “resting phase”. In Experiment 1, internal temperature logs showed that the core temperature of a steak did not drop during the two minute resting phase period. This finding proves that the steak continues to cook even when it is removed from the heat source. To further explore this resting phase period, 5 steaks of varying weights were heated for varying amounts of time on the hot plate and the lateral cross-section of each steak was photographed every minute for 5 minutes in the resting phase. Results showed no browning as the cut surface of the steak was now exposed to the ambient air and cooled which stopped any browning action.

Subsequently a further three 200g steaks were purchased and the experiment repeated but this time a slice from each steak was cut off and the lateral cut face of the remaining steak was photographed every minute. This meant that when a new slice was cut, it had spent the last minute or more cooking it it’s own juices and browning was evident.

Validity, Accuracy and Reliability

All three steaks of the repeated experiment were cooked on the same position of a barbecue plate with the same heat settings on the same day and the plate was cleaned with a paper towel between each steak. They were each flipped every minute and the only variable that changed (independent variable) was the time of cooking that varied from 4 minutes to 8 minutes. A stop watch was used to ensure accurate timing.

To ensure validity of colour comparisons between photos, the Nikon camera was set manually at the same light levels, placed on a tripod and not moved between photos and the remaining sections of steak were compared using spectral analysis. As a control, a spectral analysis of the chopping board in the photo, on which the steak was sitting was also performed to ensure ambient light levels didn’t change which could easily occur if a cloud went in front of the Sun. For accuracy, I used the exact same x and y coordinates for the selected shape that was analysed, so the exact dimensions of the steak were colour analysed and the selected region was always in the central area of the steak away from the crispy surface.

Experiment 3

Experimental Sample

In Experiment 3, 12 of the heaviest steaks were used that ranged in mass from 191g to 217g. To increase the reliability and validity of the experiment these were organised in duplicates so they had an average mass ranging from 201.87g to 204.98g. Statistically these six sets of duplicate steaks had a mean of 203.27g with a standard deviation of 1.10g.

Validity, Accuracy and Reliability

All 12 steaks were cooked on the same position of a barbecue plate with the same heat settings on the same day and the plate was cleaned with a paper towel between each steak. Steaks were all flipped every minute and the only variable changed (independent variable) was the cooking time on the hot plate. A stop watch was used to ensure accurate timing and an electronic balance that was also a data logger accurately measured the mass of juices released by each steak while resting in the aluminium tray. The mass balance data logger has a listed resolution of ± 0.1g.
### Variables and Controls

<table>
<thead>
<tr>
<th>Experiment 1:</th>
<th>Title: Optimum Flipping Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent Variable</td>
<td>The flipping rate of the steak</td>
</tr>
<tr>
<td>Dependent Variable</td>
<td>The internal temperature and the surface temperature</td>
</tr>
<tr>
<td>Controlled Variables</td>
<td>Used the same hotplate that was cleaned between each steak</td>
</tr>
<tr>
<td></td>
<td>Used the same heat settings on the hotplate</td>
</tr>
<tr>
<td></td>
<td>Used the same gas settings on the BBQ</td>
</tr>
<tr>
<td></td>
<td>Steaks were from the same cut of meat</td>
</tr>
<tr>
<td></td>
<td>Steaks were sliced to 20 mm thickness each</td>
</tr>
<tr>
<td></td>
<td>Each steak was cooked precisely to eight minutes</td>
</tr>
<tr>
<td></td>
<td>Each steak was defrosted overnight and allowed to thaw for 20 hours</td>
</tr>
<tr>
<td></td>
<td>Triplicate sets of steaks were selected so they had the same average mass</td>
</tr>
<tr>
<td></td>
<td>The Data Harvest temperature sensor was placed laterally into the centre of each steak (as best as possible)</td>
</tr>
<tr>
<td></td>
<td>The Flir Thermal Imaging Camera took surface temperatures at the centre of each steak</td>
</tr>
<tr>
<td></td>
<td>A stopwatch was used to accurately time the flipping intervals</td>
</tr>
<tr>
<td></td>
<td>Each steak was left to rest in a cleaned aluminium tray for 2 minutes before it was cut in two for the cross-section photo</td>
</tr>
<tr>
<td>Experimental Controls</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment 2:</th>
<th>Title: Browning in resting phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent Variable</td>
<td>The minute intervals that the photo was taken</td>
</tr>
<tr>
<td>Dependent Variable</td>
<td>The colour of the meat</td>
</tr>
<tr>
<td>Controlled Variables</td>
<td>Used the same hotplate that was cleaned between each steak</td>
</tr>
<tr>
<td></td>
<td>Used the same heat settings on the hotplate</td>
</tr>
<tr>
<td></td>
<td>Used the same gas settings on the BBQ</td>
</tr>
<tr>
<td></td>
<td>There were 3 steaks, used in this experiment; all approximately the same size.</td>
</tr>
<tr>
<td></td>
<td>Each steak was defrosted overnight and allowed to thaw for 20 hours</td>
</tr>
<tr>
<td></td>
<td>Each steak was cooked in different set times but flipped every one minute</td>
</tr>
<tr>
<td></td>
<td>A stopwatch was used to accurately time the flipping intervals</td>
</tr>
<tr>
<td></td>
<td>Each steak had a slice cut off every minute of the resting phase and a photo taken of the lateral view of the remaining steak.</td>
</tr>
<tr>
<td></td>
<td>Camera had same manual light settings and it did not move as it was mounted on a tripod</td>
</tr>
<tr>
<td></td>
<td>Used same size shape and position on photo for spectral analysis</td>
</tr>
<tr>
<td>Experimental Controls</td>
<td>The spectral analysis of the chopping board on which the steak was sitting to ensure consistency of background light levels</td>
</tr>
</tbody>
</table>
**Experiment 3:**

**Title:** Measuring mass of juices released during resting phase

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>The cooking time of each steak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Variable</td>
<td>The mass of juice released during the resting phase</td>
</tr>
<tr>
<td>Controlled Variables</td>
<td>Used the same hotplate that was cleaned between each steak Used the same heat settings on the hotplate Used the same gas settings on the BBQ Steaks were from the same cut of meat Steaks were sliced to 20 mm thickness each Each steak was defrosted overnight and thawed for 20 hours Duplicate sets of steaks were selected with same average mass The Data Harvest temperature sensor was placed laterally into the centre of each steak (as best as possible) A stopwatch was used to accurately time the flipping intervals The steak was placed on a clean aluminium tray after it left the hot plate, so any juice can be collected The same aluminium tray was used with the same size hole through which the juice dripped into the measuring container below sitting on the mass balance</td>
</tr>
</tbody>
</table>

| Experimental Controls | - |

**Risk Assessment**

<table>
<thead>
<tr>
<th>List of possible risks</th>
<th>Likelihood H/M/L</th>
<th>Impact H/M/L</th>
<th>Risk Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burns from BBQ</td>
<td>H</td>
<td>H</td>
<td>Use tongs and follow correct lighting procedures</td>
</tr>
<tr>
<td>Spoiling your clothes</td>
<td>H</td>
<td>L</td>
<td>Wear an apron</td>
</tr>
<tr>
<td>Cuts from knife</td>
<td>M</td>
<td>H</td>
<td>Use a cutting board and sharp knife</td>
</tr>
<tr>
<td>Tripping over electric cord of mass balance</td>
<td>L</td>
<td>M</td>
<td>Make sure the electric cords are neat</td>
</tr>
<tr>
<td>Getting sick from eating the meat</td>
<td>L</td>
<td>M</td>
<td>After the meat is cooked put straight into the freezer</td>
</tr>
<tr>
<td>Electrocution</td>
<td>L</td>
<td>H</td>
<td>Make sure no water is located around electricals</td>
</tr>
<tr>
<td>Burning Data Logger lead on the hotplate</td>
<td>H</td>
<td>M</td>
<td>Wrap the lead in aluminium foil</td>
</tr>
</tbody>
</table>
Purchasing Similar Steaks

To conduct a controlled experiment with steaks it is vital that the steaks are as similar as possible in mass, shape, meat type and thickness. To fulfil this criteria Pendle Hill Meats (Figure 7) was contacted and they sliced up 36 similar steaks of 20mm thickness from the same cut of rump (Figures 8 & 9).

Each of the 36 steaks were weighed on an electronic balance (Figure 10), recorded (Figure 11), individually wrapped, and stored in the freezer.
Experiment 1: Optimum flipping rate

Experimental Overview

This first experiment involved a sample of 18 steaks sliced from the same rump of meat, organised into triplicates. These six sets of triplicate steaks had a mean of 175.66g with a standard deviation of 0.31g. The whole purpose of Experiment 1 was to determine the optimum flipping rate that produced steaks that are cooked uniformly. Flip rates of 15s, 30s, 1min, 2min, 4min and no flip at all were tested for steaks that were all cooked for a total of 8 minutes. At the conclusion of 8 minutes each steak was removed from the hot plate and placed to rest on an empty aluminium tray which was at room temperature. For the whole 10 minute duration, a Data Harvest temperature probe inserted laterally into the centre of the steak continually logged the internal temperature of each cooking steak while a FLIR Thermal Imaging Camera measured the upper surface temperature before and after each flip. By comparing these internal and external temperature readings, a rough thermal gradient was determined for each steak. Steaks with the smallest thermal variation were judged quantitatively to have the most uniform cooking procedure. A qualitative test of visually examining the cross-section of the steak was then performed and compared with the quantitative thermal results.

Due to the expansive nature of this experiment the method and results for the thermal quantitative component is first reported followed by the method and results for the qualitative photographic analysis of the cross-section of each steak at the end of the 10 minute cooking and resting phase period.

Method – (i) Thermal quantitative variation of cooked steaks

The materials used in Experiment 1 were:
- BBQ
- 1 x tongs
- 1 x cutting board
- 1 x knife
- 1 x stopwatch
- 18 x steaks
- 1 x Data Harvest data logger
- 1 x FLIR C2 Thermal Imaging Cameras
- 2 x Aluminium Trays

Procedure:
1. Purchase the steaks
2. Weigh the steaks on an electronic balance
3. Freeze the steaks
4. Defrost and allow the steaks to thaw, the night before the experiment
5. Organise triplicates of the steaks, in similar average weights
6. Insert a probe (Figure 12) into the centre of the first steak; which collects the internal temperature data of the steak
7. As soon as the steak is placed on the hot plate, turn on the stopwatch and Data Harvest datalogger
8. Flip the steak according to the allocated time. So, if this is 15 seconds, flip the steak every 15 seconds
9. Every time the steak is flipped, take a photo of the steak before and after flipping with the FLIR C2 thermal imaging camera
10. Cook each steak on the hotplate for 8 minutes. After 8 minutes, take the steak off the hotplate, with the probe still in it and place it on the aluminium tray (see set up in Figure 13)
11. Allow the steak to rest for 2 minutes and continue to take photos each minute
12. Continue using Data Harvest to log internal temperatures during resting phase

Results – (i) Thermal quantitative variation of cooked steaks
Table 1.1 Mass of individual steaks and average mass for each steak in each set of six triplicates used for Experiment 1

<table>
<thead>
<tr>
<th>Steak #</th>
<th>Mass (g)</th>
<th>Time before flipping (s)</th>
<th>Triplicate Av. Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>153.08</td>
<td>To be used for testing</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>183.83</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>178.52</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>164.09</td>
<td>15</td>
<td>175.48</td>
</tr>
<tr>
<td>3</td>
<td>166.34</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>178.24</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>183.76</td>
<td>30</td>
<td>176.11</td>
</tr>
<tr>
<td>5</td>
<td>167.08</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>176.17</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>183.65</td>
<td>60</td>
<td>175.63</td>
</tr>
<tr>
<td>19</td>
<td>170.08</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>174.49</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>183.56</td>
<td>120</td>
<td>176.04</td>
</tr>
<tr>
<td>16</td>
<td>171.88</td>
<td>240</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>175.03</td>
<td>240</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>179.49</td>
<td>240</td>
<td>175.47</td>
</tr>
<tr>
<td>10</td>
<td>173.83</td>
<td>480</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>173.39</td>
<td>480</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>178.58</td>
<td>480</td>
<td>175.27</td>
</tr>
</tbody>
</table>

**Overall Results for 4 minutes (1 flip)**

Due to the extensive nature of the experimental results (most of which are found in my logbook) I am only going to show the general process of results for my first steak tested which was Steak 10. Steak 10 was Trial 1 of the steaks that were not flipped at all during the 8 minute cooking period. Thermal imaging photographs taken every minute of the top surface of Steak 10 are shown below:

**Steak 10 (173.83 g)**
Time: 0 minutes
Side A
Surface temp. 19.5°C

*Figure 14*
Time: 1 minutes
Side A
Surface temp. 19.8°C

Figure 15

Time: 2 minutes
Side A
Surface temp. 21.3°C

Figure 16

Time: 3 minutes
Side A
Surface temp. 22.5°C

Figure 17

Time: 4 minutes
Side A
Surface temp. 27.6°C

Figure 18
Time: 5 minutes  
Side A  
Surface temp. 29.3°C  

Time: 6 minutes  
Side A  
Surface temp. 31.6°C  

Time: 7 minutes  
Side A  
Surface temp. 34.8°C  

Time: 8 minutes  
Side A  
Surface temp. 39.9°C
As this steak was not flipped at all during the 8 minutes, there are no thermal readings for Side B as that side was always cooking away on the hotplate. Also I did not get a final reading at the 10 minute mark.

Graph 1.1 Data logger generated graph for internal temperature of Steak 10 during the 8 minute cooking phase with no flips and the 2 minute resting phase

There was a definite constant increase in temperature during the 8 minutes that Steak 10 was cooking on the hot plate. The most interesting feature, however, was the continual temperature increase for the next 30 seconds, even though it was removed from the heat source. This phenomenon will be repeated in the subsequent 17 trials and the reason for this staggering result will be further examined in Experiments 2 and 3.
Table 1.2 Compilation of internal (Data Harvest data logger) and external temperature data (FLIR thermal imaging camera) results for Steak 10

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>Side A Temp. (°C)</th>
<th>Side B Temp. (°C)</th>
<th>Internal Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>19.5</td>
<td>8.6</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>19.8</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>21.3</td>
<td>23.4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>22.5</td>
<td>32.8</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>27.6</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>29.3</td>
<td>47.4</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>31.6</td>
<td>53.6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>34.8</td>
<td>58.5</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>39.9</td>
<td>62.5</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>26</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>59.2</td>
<td></td>
</tr>
</tbody>
</table>

Graph 1.2 Comparing internal and external temperature data for Steak 10 during the 8 minute cooking phase with no flips and the 2 minute resting phase

Similar results were obtained for Steaks 11 and 17 which were Trial 2 and 3 for the steaks which were not flipped at all during the 8 minute period, see Graphs 1.3 and 1.4
Graph 1.3 Comparing internal and external temperature data for Steak 11 during the 8 minute cooking phase with no flips and the 2 minute resting phase

Graph 1.4 Comparing internal and external temperature data for Steak 17 during the 8 minute cooking phase with no flips and the 2 minute resting phase

Graph 1.5 Comparing overall results for steaks that were not flipped - Trials 1, 2 & 3
In the comparison Graph 1.5, the thermal results (tan brown trendlines) using the Flir Thermal Imaging Camera look very consistent. The data logger measurements of the internal core temperature of the steaks (orange red trendlines) are not as consistent. Trial 1 and Trial 2 are fine but Trial 3 is generally 15-20 °C higher than the other trials. My reasoning for this anomaly is that the data logger temperature probe for Trial 3 may have been too close to one side and it was that side that was on the hot plate for the whole time.

Therefore Graph 1.6 is the modified version of Graph 1.5 with Trial 3 neglected. I saw later that this will be a recurring feature of my analysis as it was extremely difficult to get the temperature sensor precisely in the centre of the steak.

Graph 1.6 Comparing similar results for steaks that were not flipped - Trials 1 & 2

By removing Trial 3 results, I now had some consistency of results and by averaging these similar trials, the following final graph is obtained for the steaks which did not get flipped.

Graph 1.7 Final Average graph for steaks that were not flipped
Using the same process of graphing the individual Side A and Side B temperatures and internal temperatures for the remaining sets of triplicates, the following composite graphs and average graphs were obtained for the steaks that were flipped every 4 minutes, 2 minutes, 1 minute, 30 seconds and 15 seconds.

**Overall Results for 4 minutes (1 flip)**

Graph 1.8 Comparing similar results for steaks flipped every 4 minutes

These three trial results are very close to each other which shows that my results are very reliable and reproducible. I was worried that the Data Harvest temperature sensor poked through the side of the steak will yield results that will fluctuate as each steak has varying thicknesses at different points of the steak, even though they were all sliced at 20mm from the same rump cut of meat. Also the FLIR thermal imaging camera was very sensitive so if I pointed it at a slightly different position on the steak, the temperatures would change. So I had to be careful that I pointed the camera at the same position of the steak every time.

Graph 1.9 Final Average graph for steaks flipped every 4 minutes
Overall Results for 2 minutes (3 flips)

Graph 1.10 Comparing similar results for steaks flipped every 2 minutes

This is the set of data where the data logger failed to start (probably my human error) for Trial 2 so I only had duplicates of the internal core results and Trial 1 (shown in pink) is very up and down which is an indicator that the probe was closer to Side B than Side A. Despite, this the thermal results of the top surface, which is recorded separately with the FLIR Thermal Imaging Camera, are in triplicates and are each very similar for each time period shown above.

The other pattern that is readily observed in the averages graph below is that the rate of cooling of the top surface is similar for each time period as the slopes are all parallel with the same negative gradient.

Graph 1.11 Final Average graph for steaks flipped every 2 minutes
Once again, the experimental method used is most reproducible as each trial replicated the other. It needs to be remembered that these trials were cooked a couple of hours apart and each steak has its own shape and fat distribution characteristics, although they were all from the same cut of rump.

The criss-cross nature of the Side A and Side B results demonstrate that the Data Harvest temperature probes must have been very well centred as each side heated and cooled at similar rates when flipped. The other significant feature is that the surface temperatures were always consistently close to the centre core temperatures which means that flipping every minute yields uniform temperature gradients in a cooking steak, which is what I am looked for.

Graph 1.12 Comparing similar results for steaks flipped every 1 minute

Graph 1.13 Final Average graph for steaks flipped every 1 minute
Very consistent results once again for all 3 trials, however it is clearly seen that the surface temperatures are well above the central core temperatures so the heat from the hot plate is not effectively penetrating to the centre as the steak is flipped before the heat can reach the centre, producing a classic medium rare steak if the steak is removed at the 6 minute mark (50°C + resting time).

The other interesting feature that is highlighted by the averages graph below is that the core temperature of the steak continues to rise by 3-4°C after the steak is taken off the hot plate and placed in the cool aluminium tray. The juices also start pouring off the steak during this resting phase - something I am pursuing in Experiments 2 and 3.
Just like the 30 second flipping results, the difference between the central core temperatures and the surface temperatures is very evident and actually amplified in the first few minutes of these results. When flipping every 15 seconds, the upper surface temperature remains around 70-80°C for the duration. Meanwhile the central core temperature reaches 40°C after 4 minutes and only 46°C after 4 minutes which is more typical of a rare steak.

Again, the similarity between the heating curves of each trial is very evident and makes these results I have obtained very reliable.
Method – (ii) Spectral Analysis

After comparing the thermal qualities of the heating process for each steak, the next mode of comparison was looking at the consistency of the colour of the cooked meat.

1. Allow the cooked steal to rest in an aluminium tray for 2 minutes
2. After 2 minutes is over, stop the data logging, remove the temperature sensor and cut the steak in two at a point of even thickness.
3. Use the FLIR thermal imaging camera to take a photo of the lateral cross-section of the steak (note: this step of the procedure was later dropped due to lack of thermal resolution)

![Figure 24]

4. Take a close-up photo of the lateral cross-section with a Nikon camera (no flash)

![Figure 25]

5. Use image sourced from [http://www.pisanieprac.info/2017/outback-steakhouse-careers.tech](http://www.pisanieprac.info/2017/outback-steakhouse-careers.tech) to make a subjective judgement of the level of well-doneness of the steak

![Figure 26]
6. Use selection tool and select rectangular section of lateral cross-section from the photo of the steak and analyse the spectral distribution of red pixels using histogram feature of Corel Photo Paint.

![Figure 27]

7. Record mean pixel level and standard deviation values – the lower the standard deviation the more uniform the cross-section.
8. Repeat procedure for each set of six triplicates and compare average mean and standard deviation values for each flipping rate.

Results – (ii) Spectral Analysis

As a guide, I will demonstrate how I will analyse the colour by taking the three trial samples from the steaks that were flipped every 15 seconds.

![Figure 28 - 15 second flips Trial 1]
The three spectral values are:

Trial 1: mean 163.83, standard deviation 19.69
Trial 2: mean 164.39, standard deviation 14.02
Trial 3: mean 160.45, standard deviation 18.52

These average out to be 162.89 ± 17.41, indicating that approximately 68% of the pixels lie in the red channel range of 145.47 → 180.29
Using this above method, the overall results for the six different flip lengths are as follows:

Table 1.3 Spectral analysis comparison of red pixels in cross-sections of each steak

<table>
<thead>
<tr>
<th>Flip rate</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 seconds</td>
<td>163.83 ± 19.69</td>
<td>164.39 ± 14.02</td>
<td>160.45 ± 18.52</td>
<td>162.89 ± 17.41</td>
</tr>
<tr>
<td>30 seconds</td>
<td>161.60 ± 16.30</td>
<td>156.07 ± 17.78</td>
<td>145.43 ± 21.40</td>
<td>154.37 ± 18.49</td>
</tr>
<tr>
<td>1 minute</td>
<td>141.18 ± 17.73</td>
<td>157.79 ± 16.42</td>
<td>147.77 ± 23.27</td>
<td>149.08 ± 19.14</td>
</tr>
<tr>
<td>2 minutes</td>
<td>151.47 ± 22.89</td>
<td>159.93 ± 20.62</td>
<td>137.92 ± 18.41</td>
<td>149.77 ± 20.64</td>
</tr>
<tr>
<td>4 minutes</td>
<td>149.24 ± 23.14</td>
<td>151.24 ± 22.24</td>
<td>134.69 ± 16.24</td>
<td>145.06 ± 20.54</td>
</tr>
<tr>
<td>8 minutes (no flip)</td>
<td>159.92 ± 21.33</td>
<td>140.88 ± 28.05</td>
<td>142.13 ± 24.95</td>
<td>147.66 ± 24.77</td>
</tr>
</tbody>
</table>

Graph 1.18 Comparison of Internal Core Temperatures in relation to Flipping times
The general trend is that the redness does change to a darker red (or brown to be precise) as the flip rate decreases. On the RGB colour wheel for the red channel, 255 is fully red and 0 is no red, so 162.89 is redder than 147.66. Therefore the colour of the cross-section shows that the centre was more cooked in the centre as the flip rate was reduced. So for the steaks that were flipped every 15 seconds, the heat was not given the opportunity to penetrate to the centre of the steak so the centre of the steak remained red, or raw in cooking terms. In contrast the steak that was flipped just once was most cooked in the centre, even more that the steak that was not flipped at all. It does need to be pointed out that the final colour of the cooked meat was quite similar for steaks that were flipped every minute, 2 minutes, 4 minutes and not flipped at all – for steaks that are left on the hot plate for 8 minutes.

The second consideration and probably the most important aspect of having a well-cooked steak is the uniformity of the cooking process. The 8 minute (no flip) steak had the greatest variation of colour with a standard pixel deviation of 24.77. This was clearly apparent in Figure 31, where the top of the steak was red raw as it never touched the hot plate, while the bottom was clearly well done. No chef would receive complements if this variably-cooked steak was served up to a customer! Interesting enough, the steaks with the highest frequency of flipping had the least variation in their spectral frequency histogram and therefore had the greater uniformity of cooking consistency.

Conclusion of colour comparison of steak cross-sections

Based on the level of cooking at the centre and the uniformity of the cooking, I would have to say that the steaks flipped every minute, produced the best looking steaks and the steaks that were not flipped at all resulted in the worst looking steaks. However, the 30 second flips and the 2 minute flips were very close behind.
**Experiment 2: Browning in resting phase**

**Experimental Overview**

A qualitative study of the spectral distribution of the pixel colours were analysed using a spectral frequency histogram for Experiment 2. Steaks cooked for 4min, 6min and 8min each flipped every minute were then sliced once every minute during the resting phase to see if the steaks browned while resting. The steak cooked for 6 minutes continued to cook the most while in this resting phase.

**Method – Browning in resting phase**

The materials used in Experiment 2 were:

- 1x aluminium tray
- 1x thongs
- 1x knife
- BBQ
- 1x Camera (Nikon)
- 1x Cutting board
- 3x steaks
- 1x stopwatch

**Procedure**

1. Purchase three similar steaks *(Figure 32)*
2. Defrost and allow the steaks to thaw, the night before the experiment
3. Weigh the steaks *(Figure 33)*
4. Place the first steak on the hotplate
5. Cook the first steak for 4 minutes, flipping it every minute
6. After cooking, place the steak on a cutting board and carefully use a knife to slice of a section, labelled ① in *Figure 34*.
7. Immediately, using a Nikon camera on manual setting and on a tripod take a photo of the lateral cross-section of the steak that remains.
8. After one minute, cut a second slice, labelled ② in *Figure 35* and take photo of remaining steak.
9. Repeat with third, fourth …. slices at one minute intervals.
10. Repeat steps 5-9 for the second steak with the only difference being that it is cooked for 6 minutes, still getting flipped every minute.
11. Repeat steps 5-9 for the third steak with the only difference being that it is cooked for 8 minutes, getting flipped every minute.
12. Load each photo onto Corel Photo Paint and use the histogram feature, using the red channel to measure the mean red pixel count and the standard deviation for a selected rectangular section of each cross-section.
13. As an experimental control, measure the spectral distribution using the full RGB settings so the background and light levels of each photo can be standardised to 120. Therefore fluctuating light levels due to cloud movement will be standardised.
14. Compare changes in red colour for each steak during the resting phase

**Results – Browning in resting phase**

**Steak Cooked for 4 Minutes**

<table>
<thead>
<tr>
<th>Time of photograph</th>
<th>Steak Red Channel</th>
<th>Steak RGB Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 min</td>
<td>144.60 ± 16.11</td>
<td>111.34 ± 19.60</td>
</tr>
<tr>
<td>7 min</td>
<td>128.43 ± 15.49</td>
<td>95.27 ± 15.70</td>
</tr>
<tr>
<td>6 min</td>
<td>130.37 ± 24.69</td>
<td>98.99 ± 25.14</td>
</tr>
<tr>
<td>5 min</td>
<td>154.39 ± 25.16</td>
<td>121.89 ± 30.00</td>
</tr>
</tbody>
</table>

**Table 2.1** Raw spectral analysis data for both Red and RGB colour settings for 4 min steak

<table>
<thead>
<tr>
<th>Time of photograph</th>
<th>Steak Red Channel</th>
<th>Steak RGB Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 min</td>
<td>153.26 ± 16.11</td>
<td>120.00 ± 19.60</td>
</tr>
<tr>
<td>7 min</td>
<td>153.16 ± 15.49</td>
<td>120.00 ± 15.70</td>
</tr>
<tr>
<td>6 min</td>
<td>151.38 ± 24.69</td>
<td>120.00 ± 25.14</td>
</tr>
<tr>
<td>5 min</td>
<td>152.50 ± 25.16</td>
<td>120.00 ± 30.00</td>
</tr>
</tbody>
</table>

**Table 2.2** Adjusted Red channel spectral distribution readings after standardising RGB values to 120 for 4 min steak.
Steak Cooked for 6 Minutes

Table 2.3  Raw spectral analysis data for both Red and RGB colour settings for 6 min steak

<table>
<thead>
<tr>
<th>Time of photograph</th>
<th>Steak Red Channel</th>
<th>Steak RGB Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 min</td>
<td>145.13 ± 17.36</td>
<td>122.67 ± 19.13</td>
</tr>
<tr>
<td>9 min</td>
<td>143.63 ± 18.76</td>
<td>122.51 ± 22.31</td>
</tr>
<tr>
<td>8 min</td>
<td>143.25 ± 21.62</td>
<td>116.95 ± 23.19</td>
</tr>
<tr>
<td>7 min</td>
<td>138.28 ± 18.06</td>
<td>111.28 ± 20.08</td>
</tr>
</tbody>
</table>

Table 2.4 Adjusted Red channel spectral distribution readings after standardising RGB values to 120 for 6 min steak.

<table>
<thead>
<tr>
<th>Time of photograph</th>
<th>Steak Red Channel</th>
<th>Steak RGB Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 min</td>
<td>142.46 ± 17.36</td>
<td>120.00 ± 19.13</td>
</tr>
<tr>
<td>9 min</td>
<td>141.12 ± 18.76</td>
<td>120.00 ± 22.31</td>
</tr>
<tr>
<td>8 min</td>
<td>146.30 ± 21.62</td>
<td>120.00 ± 23.19</td>
</tr>
<tr>
<td>7 min</td>
<td>147.00 ± 18.06</td>
<td>120.00 ± 20.08</td>
</tr>
</tbody>
</table>
Steak Cooked for 8 Minutes

Table 2.5  Raw spectral analysis data for both Red and RGB colour settings for 8 min steak

<table>
<thead>
<tr>
<th>Time of photograph</th>
<th>Steak Red Channel</th>
<th>Steak RGB Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 min</td>
<td>161.49 ± 27.03</td>
<td>134.81 ± 30.26</td>
</tr>
<tr>
<td>12 min</td>
<td>150.69 ± 27.84</td>
<td>124.24 ± 32.91</td>
</tr>
<tr>
<td>11 min</td>
<td>110.30 ± 23.41</td>
<td>84.44 ± 24.84</td>
</tr>
<tr>
<td>10 min</td>
<td>127.44 ± 22.96</td>
<td>97.88 ± 24.42</td>
</tr>
<tr>
<td>9 min</td>
<td>118.37 ± 24.88</td>
<td>90.89 ± 26.36</td>
</tr>
</tbody>
</table>

Table 2.6 Adjusted Red channel spectral distribution readings after standardising RGB values to 120 for 8 min steak.

<table>
<thead>
<tr>
<th>Time of photograph</th>
<th>Steak Red Channel</th>
<th>Steak RGB Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 min</td>
<td>146.68 ± 27.03</td>
<td>120.00 ± 30.26</td>
</tr>
<tr>
<td>12 min</td>
<td>146.45 ± 27.84</td>
<td>120.00 ± 32.91</td>
</tr>
<tr>
<td>11 min</td>
<td>145.86 ± 23.41</td>
<td>120.00 ± 24.84</td>
</tr>
<tr>
<td>10 min</td>
<td>149.56 ± 22.96</td>
<td>120.00 ± 24.42</td>
</tr>
<tr>
<td>9 min</td>
<td>147.48 ± 24.88</td>
<td>120.00 ± 26.36</td>
</tr>
</tbody>
</table>
Discussion – Browning in resting phase

Each photo had a greater variation in light levels than I originally anticipated. As a result, this method of standardising the results for the fluctuation of light levels worked really well. I standardised all the RGB Channel values to 120.00. The mean red pixel count for the steak cooked for 4 minutes was very consistent around the 152 value.

The steak portions with the greatest visual variation were from the steak that was cooked for 6 minutes. Visually the bottom two layers are much redder than the top two layers. This is reflected in the quantitative values obtained through spectral analysis. The bottom two layer had a redness value of around 147 while the two upper layers had a redness value of around 142 so there was a measurable difference to support the qualitative observations.

Finally, for the portions of the steak that were cooked for 8 minutes, the differences in the redness were negligible. All the spectral redness values were around 147 and visually they were all similar.

In conclusion, Experiment 2 showed that for the resting phase there is a greater level of extra cooking or browning for steak that is cooked for 6 minutes, as opposed to 4 minutes and 8 minutes. This is somewhat supported by the juices released in Experiment 3 (see below) where the steak cooked for 6 minutes released more juices than 4 and 8 minutes. Regretfully I didn’t test the browning for 10 minutes, which would have been useful in retrospect.

Experiment 3: Measuring mass of juices released in resting phase

Experimental Overview

This final experiment with 12 steaks organised into duplicates, sought to measure the mass of the juices that were released during the resting phase for steaks cooked for 2min, 4min, 6min, 8min, 10min and 12min, with each steak being flipped every minute. Chefs are fully aware of the juices that are released from steaks during this resting phase and hence deliberately wait a few minutes before plating up so steak juice does not spoil the overall presentation of a serving. Experiment 1 also showed that the release of these juices play an important role in the transfer and sustainance of heat during this resting phase. A special electronic balance with a data logging facility will be utilised to measure both the rate and release duration of juices from steaks during this resting phase.
Method – Measuring mass of juices released in resting phase

The materials used in Experiment 3 were:

- 1x tongs
- 1 aluminium trays with hole punctured in one corner
- BBQ
- 1x stopwatch
- 12x steaks
- 1x Camera (Nikon)
- 1x Data Harvest datalogger with temperature sensor
- 1x TLI Mass-Balance
- 1x Interface cable
- 1x Laptop with TLI Mass-Balance software
- 1x metal bowl

Table 3.1 Mass of individual steaks and average mass for each steak in each set of six duplicates used for Experiment 3

<table>
<thead>
<tr>
<th>Steak #</th>
<th>Mass (g)</th>
<th>Trial name</th>
<th>Average Trial mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>190.88</td>
<td>2 minute Trial 1</td>
<td>203.86</td>
</tr>
<tr>
<td>34</td>
<td>216.83</td>
<td>2 minute Trial 2</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>193.38</td>
<td>4 minute Trial 1</td>
<td>204.98</td>
</tr>
<tr>
<td>29</td>
<td>216.57</td>
<td>4 minute Trial 2</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>193.48</td>
<td>6 minute Trial 1</td>
<td>201.91</td>
</tr>
<tr>
<td>28</td>
<td>210.34</td>
<td>6 minute Trial 2</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>194.19</td>
<td>8 minute Trial 1</td>
<td>201.87</td>
</tr>
<tr>
<td>31</td>
<td>209.54</td>
<td>8 minute Trial 2</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>200</td>
<td>10 minute Trial 1</td>
<td>203.38</td>
</tr>
<tr>
<td>30</td>
<td>206.76</td>
<td>10 minute Trial 2</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>203.53</td>
<td>12 minute Trial 1</td>
<td>203.64</td>
</tr>
<tr>
<td>23</td>
<td>203.75</td>
<td>12 minute Trial 2</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>203.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>standard deviation</td>
</tr>
</tbody>
</table>

Procedure

1. Purchased the steaks
2. Weighed the steaks
3. Defrosted and let the steaks thaw the night before the experiment
4. Connected a computer to the TLI Mass-Balance and zeroed the balance
5. Inserted temperature probe into the first steak, Steak #4
6. Started data logger recording and TLI Mass-Balance recording simultaneously as Steak 4 was added to the hotplate

![Figure 36 – Experimental procedure for Experiment 3](image)

7. Steak 4 was left on the hot plate for precisely 2 minutes, having been turned at the one minute mark
8. Using tongs, Steak 4 was then taken from the hot plate and placed in the aluminium tray.
9. The aluminium tray was positioned on an incline with the punctured hole in the bottom corner receiving the juices that were released from the steak in the resting phase.

![Figure 37 - Released juices running down towards the hole in the corner](image)
10. A metal bowl sitting on top of the TLI Mass-Balance received the juices dripping from the aluminium tray

11. The trial stopped when the juices stopped running from the steak.
12. Repeat steps 5-11 with Steak 34, the duplicate pair of Steak 4
13. Repeat steps 5-11 for the remaining 10 steaks in the order they are shown in Table 3.1. The only difference is that the pairs of steaks are cooked for 4min, 6min, 8min, 10min and finally 12min, with each steak being flipped on the hot plate every minute
14. Compare the results and determine which duration of cooking produces the most juices during the resting phase.

Figure 38 - Juices starting to collect in the bowl and be logged by the TLI Mass-Balance software

Figure 39 - Some steaks such as Steak 32 (193.48g) which was cooked for 6 minutes still retained a lot of its’ moisture and released 2.9% of its’ original weight as the meat tissues relaxed during this resting phase.
Experiment 3 – Experimental set-up explained pictorially

- Steak 32 being cooked for 6 minutes
- Expert cook now onto my 28th steak
- Data logger temperature sensor monitoring internal core temperatures
- Data logger recording core temperatures
- Last remaining 7 steaks lined up ready to cook
- Aluminium tray with hole on tilted base
- Computer interfaced with balance collecting mass data
- Logical Interface data balance collecting juices
Results – Measuring mass of juices released in resting phase

2 Minute Trial 1 Results

Juice Mass (g) for 2 minutes Trial 1

Juice Released: 1.28g
Juice Mass (g) for 2 minutes Trial 2

Juice Released: 0.31g
4 Minute Trial 1 Results

Juice Released: 3.47g
4 Minute Trial 2 Results

**Juice Released:** 2.77g
Juice mass (g) for 6 minute Trial 1

Juice Released: 4.83g
Juice mass (g) for 6 minutes Trial 2

Juice Released: 2.83g
8 Minute Trial 1 Results

Juice mass (g) for 8 minutes Trial 1

Juice Released: 2.83g
8 Minute Trial 2 Results

Juice Released: 4.61g
10 Minute Trial 1 Results

10 Minute Trial 2 Results
Juice mass (g) for 10 minutes Trial 2

Juice Released: 5.90g

12 Minute Trial 1 Results
12 Minute Trial 2 Results

Overall Results of Experiment 3

Table 3.2 Overall results of juices release for each trial in Experiment 3

<table>
<thead>
<tr>
<th>Time cooked and flipped every 1 min</th>
<th>Mass of Juice released in ‘Resting phase’</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1 (g)</td>
</tr>
<tr>
<td>2 min</td>
<td>1.28</td>
</tr>
<tr>
<td>4 min</td>
<td>3.47</td>
</tr>
<tr>
<td>6 min</td>
<td>4.83</td>
</tr>
<tr>
<td>8 min</td>
<td>2.83</td>
</tr>
<tr>
<td>10 min</td>
<td>approx 5.00</td>
</tr>
<tr>
<td>12 min</td>
<td>approx 3.00</td>
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</tbody>
</table>
Discussion – Measuring mass of juices released in resting phase

Although the mass was showing on the screen of the balance, I was unaware that the computer was recording values around 0g for 3 of the last 4 readings. I am pretty confident that my approximations are correct as I noted that 10 min were the highest out of all the readings and their was a definite drop-off for the 12 minute steaks.

There was a good deal of variation of juice released for this experiment, especially within each duplicate set. There was a general upwards trend for the amount of juice released until the 10 min mark. After that point, dehydration due to overcooking would most likely have been taking place.

In all cases, it was quite amazing to examine how the steaks took around a minute for the pores to start releasing the juices in this “resting phase”. Then all of a sudden the juices started to run out and this added moisture would have provided a medium for the heat to be conducted around the steak which would have influenced the increase of temperature that existed in the centre of the steak when the steak is removed from the hotplate.

Conclusion

My hypothesis was to flip the steak every 30 seconds as recommended by Harold McGee. Although this flip rate did rate highly for uniformity of cooking, the ultimate flip rate was 1 minute. From the use of thermal imaging cameras, data logging temperature probes and spectral analysis software I have some definite findings that flipping the steak every minute gives the most consistent and uniform level of cooking. Also if you want the juiciest steak on a great Aussie BBQ where you just have a hotplate with no bells or whistles, cook the steak for 6 minutes. You will get a medium rare steak that is cooked evenly and if you allow it to rest for a few minutes it will allow the excess juices to run off, however, it will still be hot, juicy and delicious.

Further Research

The whole focus of my project was simulating the Great Aussie BBQ, where you slap a steak onto a hotplate, and allow it to cook in its own natural juices. Now that I have accomplished this task I want to go one step further and cook a steak in oil on a fry pan to see if I can work out which world celebrity chef if using a procedure that produces the perfect steak.
Acknowledgments

My Science Teacher- I would like to thank him for helping me with my experiment since the beginning, for organising the thermal imaging cameras and being there when each of the three experiments were performed. I would like to thank him for helping me compile all the data in a manner that has some order. He gave up countless afternoons to assist me in the formatting of this report and logbook.

My Mentor- I would like to thank our food technology teacher who served as my mentor - checking my background research and making sure that my experimental procedure was correct before launching into an experiment.

My Mum and Dad- Thank you for purchasing the steaks; that were essential for this project. Thank you mum and dad for encouraging me to finish my report even when it was late at night, and helping me.

Flir Systems Australia – They allowed me to borrow a Thermal Imaging Camera.

Pendle Hill Meats- They cut all the 37 steaks as similar as possible, each 20 mm each.

References

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