# STUDIES OF AN EXPERIMENTAL GEYSER MODEL

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## Research question:

How does changing the pressure, amount of water and power supply affect the boiling points and eruptions of an experimental geyser-model?

This research is dedicated to Egil Kvam (1960-2010)

an infinite source of encouragement and support

# 1. Abstract

The objective of this investigation is to examine how changing the pressure, amount of water and power supply affects the boiling points and eruptions of an experimental geyser-model. The model is made by heating water in a flask. The water will erupt by creating water vapor which travels up a tube and into a container of cold water. After the eruption water from the container travels down the tube, cooling the water in the flask and the cycle starts over. This is an example of a self-oscillatory system.

The water pressure in the flask is dependent on the height of the geyser and it determined how high temperatures the experimental geysers reached, namely the boiling points. The path the water vapor took to reach the surface determined how much energy was lost on the way. The amount of water added above the tube in the container did not have much effect on pressure, but it was clear from graphs and observations that it determined how much the reaction was damped, hence how explosive the eruptions are. The power of heating had an effect on the intensity of the eruptions and how quickly they occurred.

The eruptions however remain a mystery as the intervals between each eruption and their durations are deterministic chaos. There are no distinct trends all the geysers follow, and exceptions to every observation.

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## 2. Introduction

### 2.1 Background

A geyser is defined by geologists with the U.S Geology Survey as "A hot spring characterized by intermittent discharge of water ejected as a turbulent eruption that is accomplished by a vapor phase"[1]. Geysers are only found in some areas of the world. The most famous are situated in Yellowstone National Park and Iceland. The geysers are very fragile systems dependent on many factors in order to function. Because of the delicacy many geysers have disappeared through the years[2] some due to nature and others due to human interference. It is important to investigate the phenomena and gain a better understanding of it, in order to keep these wonders for future generations. This subject is relevant in connection to physics because it is a physical phenomenon created due to high pressure and superheated water.

### 2.2 Objective

**The objective of this investigation is to examine how changing the pressure, amount of water and power supply affects the boiling points and eruptions of an experimental geyser-model.**

## 3. The design

### 3.1 The natural geyser

There are some fundamental requirements in order for a hot spring to be classified as a geyser. A German chemist named Robert W. Bunsen concluded that you would need heat, lots of water, an underground plumbing system and the right kind of water chemistry[3]. The minerals required in the water narrows the underground path which helps create the pressure necessary for an eruption. The water gets superheated due to the pressure, but eventually starts boiling. Bubbles of gas cause the water to expand and exert pressure on the water above. As vapor fills the underground plumbing system the pressure of the water will decrease and the boiling increases. That is what leads to the steam which rises to the surface and causes the eruption[4]. This system is what I will try to copy with my experimental geyser-model.

[1] Geysers – What They Are and How They Work p.15
[2] Geysers – When Earth Roars p.54
[3] Geysers – When Earth Roars p.47-49
[4] Geysers – When Earth Roars p.49

**3.2 Setup**

The setup is shown in Figure 1. An Erlenmeyer flask was placed on a hot plate and a rubber stopper with two holes sealed the neck of the flask. In one hole a temperature sensor was placed, and in the other a plastic tube. The other end of the tube was attached to a second rubber stopper which was placed through a hole in the bottom of a plastic container. The container was positioned well above the flask on top of a supporting ring. Another temperature sensor is placed in the container and a data logger is used to measure the temperature in both the flask and the container at the same time. Water is poured into the system until it reaches a level a couple of centimeters above the stopper in the container. Unlike in a real geyser I used pure water, but I don't think it was significant as the minerals are present to narrow the path and create pressure; I managed to do that with the thin tube and the rubber stoppers.

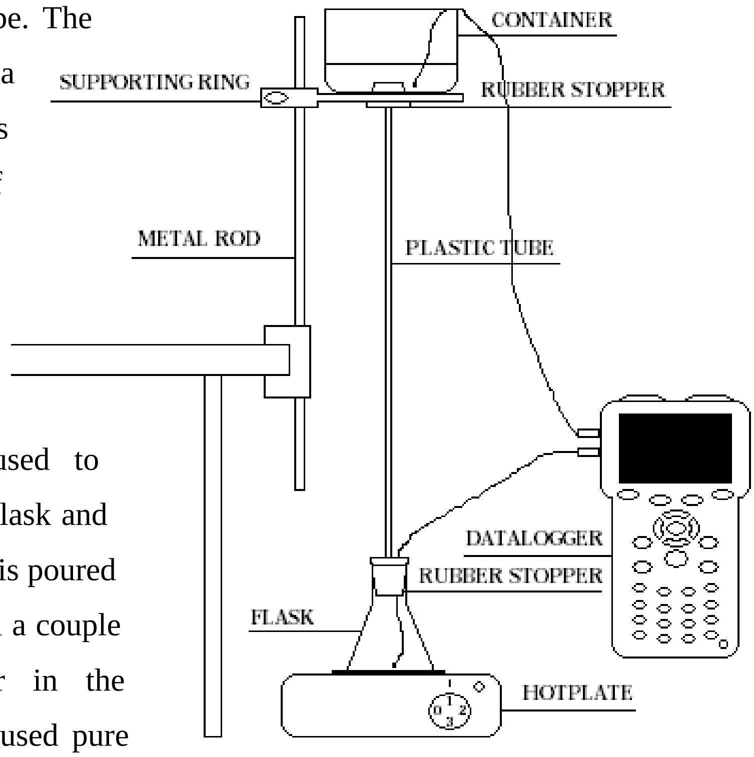


**Figure 1 – The setup**

The original setup was somewhat different, but I changed it during my preliminary experiments to better suit the nature of my investigation. At first I used a Bunsen burner, but I found it was too difficult to control the flame, and it contained too little gas to last throughout all of the experiments. I originally used a glass pipe instead of a plastic tube, but the selection of different lengths was limited, and with a plastic tube I could cut desired lengths.

### 3.3 Physical principles

The pressure exerted on water is equal at all points in a horizontal level, but dependent on the depth of the water. This is proven by the following formula for pressure where **h** represents the height of the system[5]:

$$P = \rho g h$$

Increasing pressure results in an increase in the water's boiling point, as the vapor pressure of the water must equal the pressure exerted upon it for boiling to occur. As the water eventually boils water vapor will be created in the flask, and when the pressure is high enough it will move upwards through the tube and into the container. However, as it reaches the container it will have to penetrate a layer of cooler water. The cold water will be pushed upwards into eruption by the steam and create a partial condensation as some of the gas goes back to being water. The result is an eruption of steam and water, the pressure is decreased and the water is desuperheated. This will drain the flask for some of its content, which will be replaced by water from the container. Then the process starts over again, making it a self-oscillatory system.

### 3.4 Variables

I chose three independent variables which I altered in turn to investigate how they would affect the properties of the geyser-model; height, amount of water and power supply. I measured the height of the geyser by the use of tape measure, the amount of water with a measuring beaker and later the water level above the stopper with a ruler and I controlled the power supply by the use of the heat regulator on the hot plate. To investigate the effect of these variables I measured the temperatures in the flask and container with the datalogger. By plotting the temperatures recorded every half second we get a graph showing how the temperature rises and drops during the cycle of the geyser. I used a stop watch to record the time between each eruption and how long they lasted, also I took qualitative notes.

### 3.5 Varying the independent variables

When varying the height of the Geyser system it was done in two different ways. First the position of the container was the only thing regulated, whilst the length of the tube was kept constant. This resulted in a bent and crooked tube between the stoppers. The second approach was to keep the tube straight when changing the height. Attempts were made to have the same

[5] Physics for the IB Diploma p. 176

various heights of water in both procedures, so that they could be compared. These two models were used in order to tell whether the underground plumbing of a geyser is significant, as the path the water must travel to get to the surface is individual from one geyser to another. When varying the amount of water in the system the apparatus was kept constant. The result was that the change in water volume was apparent in the height of the water level in the container. The power of heating was changed by regulating the setting of the hot plate which featured three different strengths; 1, 2 and 3.

Whenever one of the independent variables were changed the others were kept constant along with the rest of the characteristics according to a standard model. Table1 shows the standard conditions, which will approximately agree with the ninth geyser.

| **Standard Conditions** | |
|---|---|
| Approximate water above stopper | 0.03m |
| Approximate length of tube | 0.91m |
| Approximate height between stoppers | 0.90m |
| Height of stopper in container | 0.035±0.001m |
| Distance between top of stopper and flask | 0.008±0.001m |
| Diameter of hole in tube | 0.008±0.001m |
| Diameter of the bottom of the flask | 0.09±0.01m |
| Height of the flask | 0.145±0.001m |
| Approximate volume of water in the system | 1.4l |
| Heat adjustment on hotplate | 1 |

**Table 1 – standard geyser characteristics**

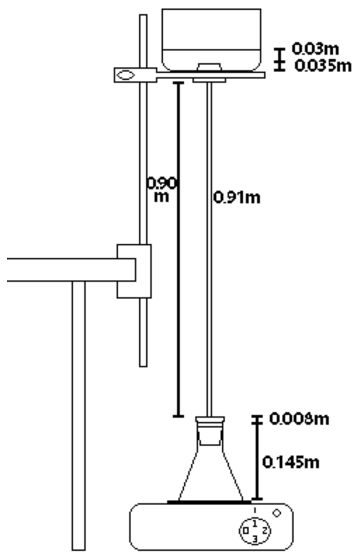


**Figure 2 – standard conditions**

# 4. Results

## 4.1 Visual observations

To make the developments of the geyser easier to follow I poured a couple of drops of confectioner color in the container, resulting in blue water in the top and clear water in the flask and tube. I assumed that this would not have a significant effect on the experiment. After a period of time bubbles of steam shot up the tube. An eruption formed which lasted several seconds, when it ended water went down the tube into the flask. This was a mixture of the water that originally had been in the container and the water from the flask which had erupted; proven by the fact that the water in the flask was now also blue, see Picture 1.

**Picture 1 – Blue water from the container entering the flask**

When the geyser erupted again the blue color proved that it was in fact water vapor and not water going up as the tube became transparent. The intensity of the eruptions varied, and during the larger eruptions some water blew out of the container, but not enough to make any significant impact. This cycle continued until the power source was turned off.

## 4.2 Graphical analysis

Figure 4 shows how the geyser is portrayed through a graph showing the changing temperatures in the flask and container. The sudden increases in temperature in the container are when the geyser erupts and hot water is mixed with the cold. Almost unanimously we can register a rapid drop in the temperature in the flask. This is when cold water from the container is sucked down. When the flask reaches approximately the same temperature as on the previous peak the pattern repeats itself. However I cannot see any understandable pattern in the time intervals between the eruptions, or within them for that matter.

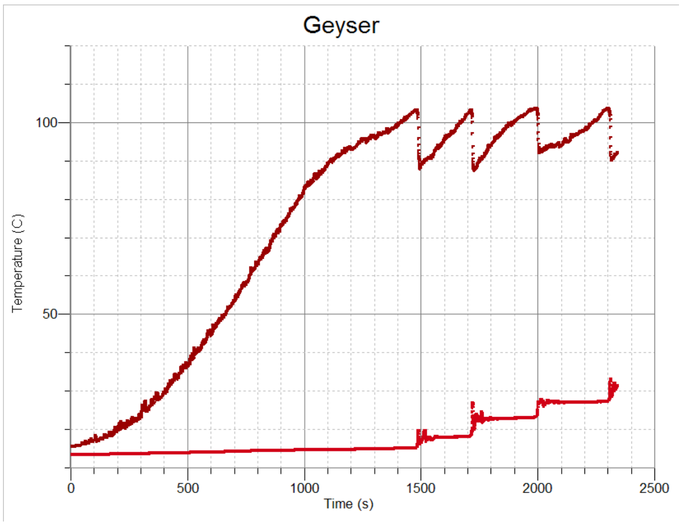


**Figure 3 – Example of a geyser graph**
**Dark line = temp in flask, Light line = temp in container**

## 5. Varying height

The position of the container is changed both with and without adjusting the tube accordingly.

### 5.1 Primary data collected – slack tubes

Table 2 shows the observations I made concerning the geysers with changing height and slack tubes. The uncertainties in the table are based on the tape measure, the stop watch, and the data logger, which all only records tenths, and so the uncertainties must be 0.1. The uncertainties when adding values are calculated by the following formula:

$$\frac{Maximum\ value - minimum\ value}{2} = uncertainty$$

| Geyser# | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Height of water level±0.005m | 1.450 | 1.373 | 1.175 | 1.112 |
| Length of tube±0.001m | 1.375 | 1.349 | 1.277 | 1.337 |
| Eruption height | Low | Low | Low | Low |
| Eruption width | Container | Container | Container | Container |
| Start time of first boil ±0.1seconds | 24:37.1 | 25:58.8 | 20:37.4 | 24:28.5 |
| Mean boiling temperature ±0.4°C | 103.6 | 103.5 | 102.5 | 102.5 |

**Table 2 – Geysers with slack tubes and varying height**

As these geysers erupted the tube oscillated, which is a phenomenon I only witnessed when using slack tubes.

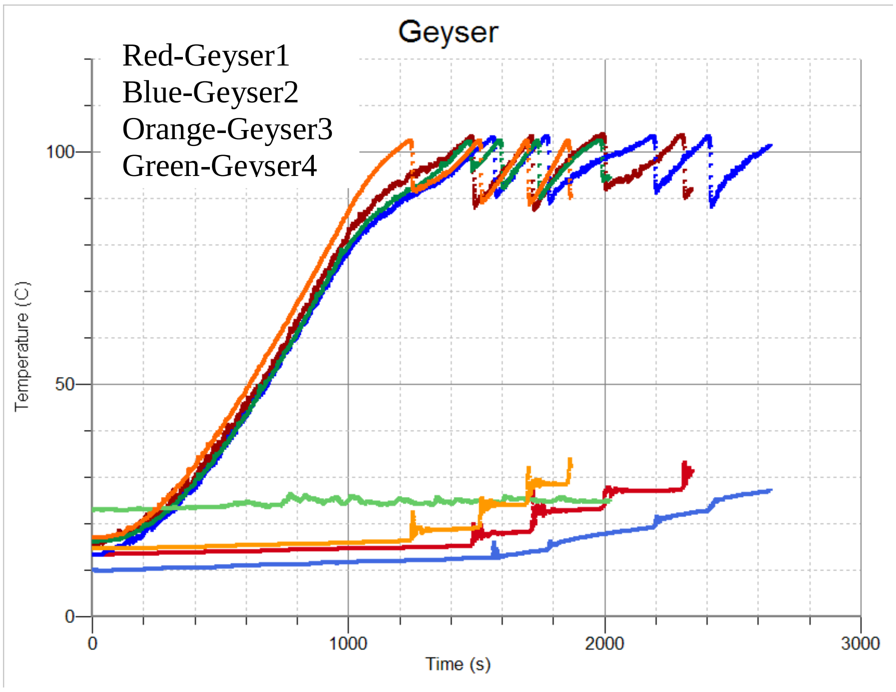


Figure 4 - The geysers with slack tubes and different heights

## 5.2 Analysis of data

The time it takes before the boiling begins seems random and not affected by the height; the intervals between the eruptions also seem irregular. This can particularly be seen in the blue lines where one interval is much longer than the others. However there appears to be a trend in how high the temperature can go; higher geysers higher boiling points. The line representing the temperature in the container of geyser 4 would seem to be an error. It could be due to the temperature probe in the container or the fact that the water used in the container was approximately 10$^{o}$C warmer than with the other geysers. However it does not seem logical that the temperature would not be affected by the eruptions, consequently this result should be disregarded as it cannot be compared to other geysers with completely different temperature starting points.

## 5.3 Primary data collected – straight tubes

The following section examines the geysers which had straight tubes.

| Geyser# | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|
| Height of water level±0.005m | 1.552 | 1.450 | 1.381 | 1.182 | 1.117 |
| Length of tube±0.001m | 1.380 | 1.250 | 1.168 | 0.962 | 0.907 |
| Eruption height | Very high | High | Medium | High | High |
| Eruption width | Very broad | Broad | Container | Broad | Broad |
| Start time of first boil ±0.1seconds | 20:07.6 | 25:40.6 | 26:45.1 | 23:31.8 | 19:39.2 |
| Mean boiling temperature ±0.4$^{o}$C | 104.0 | 102.8 | 102.7 | 102.3 | 102.1 |

**Table 3 – Geysers with straight tubes and changing height**

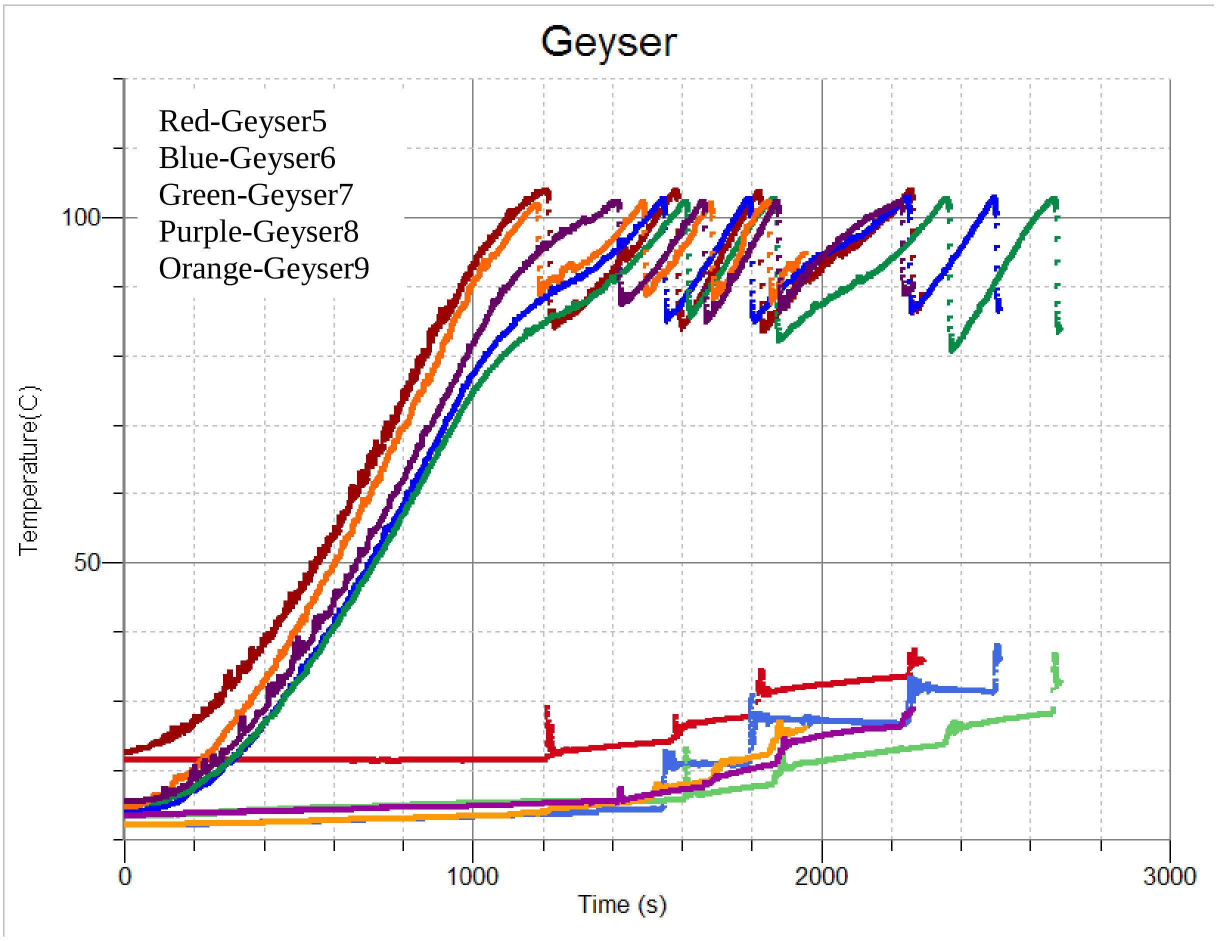


**Figure 5 – The geysers with straight tubes and different heights**

## 5.4 Analysis of data

These results support the previous statement of higher temperatures obtained when the geyser is taller. A significant difference when dealing with the straight and slack tubes was the fact that the eruptions were much larger when the tube was straight. Within the geysers the intervals still seem irregular; this is most clearly seen in the case of geyser 7.

### 5.5 Comparison of geysers with slack and straight tubes

Where Figure 5 and 6 showed the significance of changing the height, Figure 7, 8, 9 and 10 compares the geysers which had equal heights but different lengths of their tubes.

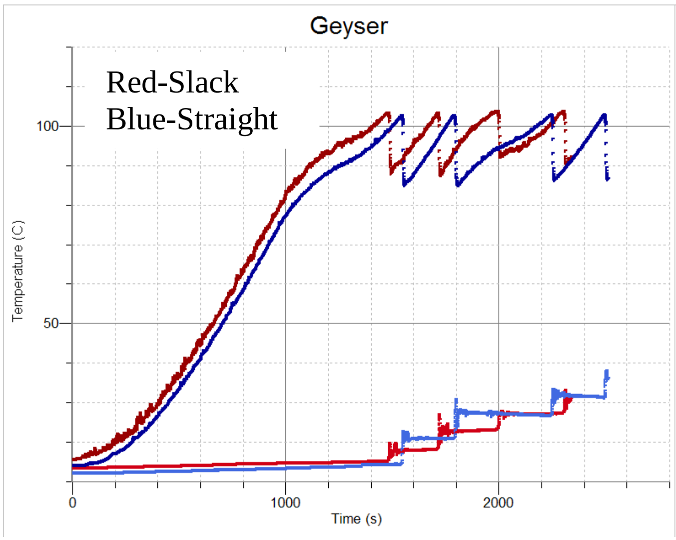


**Figure 7 – Height: approximately 1.5m**

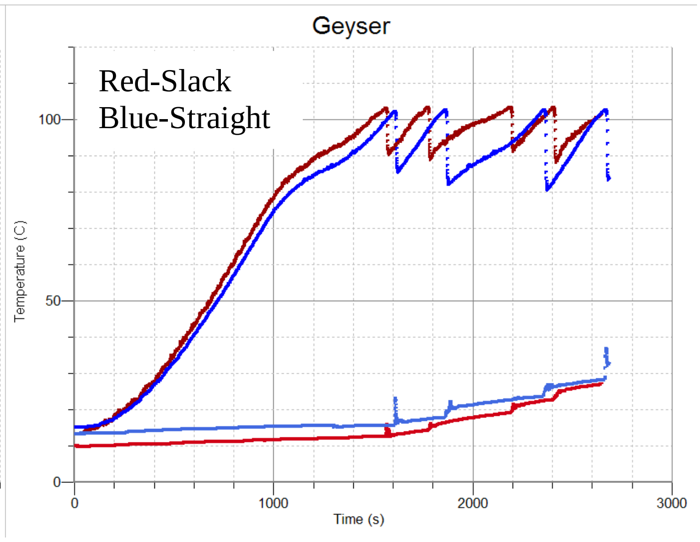


**Figure 8 – Height: approximately 1.4m**

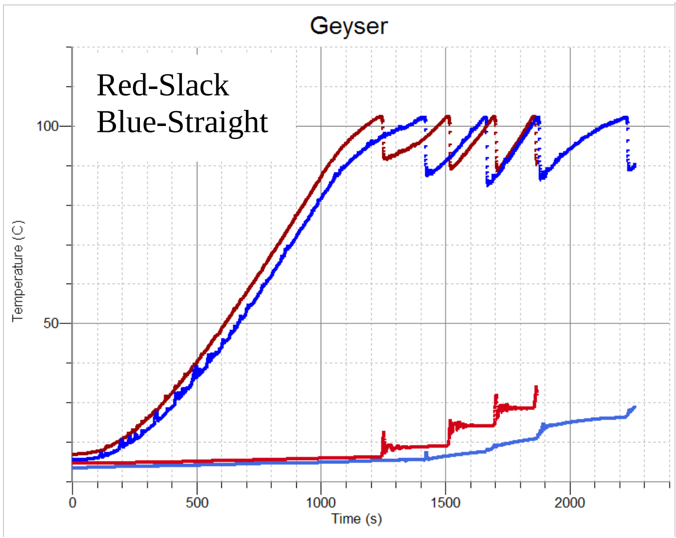


**Figure 9 – Height: approximately 1.2m**

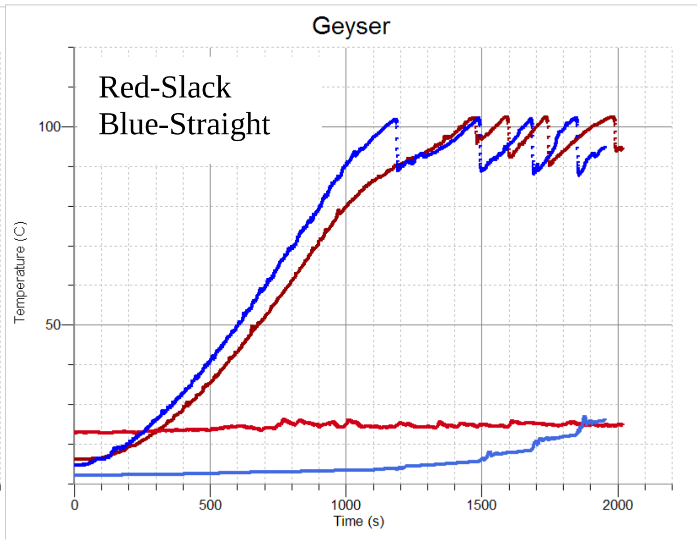


**Figure 10 – Height: approximately 1.1m**

The temperatures from the containers seem to create quite different shapes. I attribute this to the position of the probe, and chose to focus on the temperatures in the flask. A common feature is that the temperature drops further in the geysers with straight tubes, hence more cold water runs down the tube to the flask. For such a situation to arise the geysers must first have gotten rid of more water in a larger eruption. Even though the geysers experiences somewhat equal pressures they may not have an equal amount of energy as the jet of steam reached the container. In the geysers with slack tubes some energy was lost in creating vibration in the tubes and some because the water got more time to cool down before entering the container.

### 5.6 Calculations

To prove that the large geysers reached the highest temperatures we can calculate the pressures of each geyser, and hence the boiling points. The formula for the total amount of pressure is[6]:

$$\text{Total } P = \rho g h + P_{(atm)}$$

The pressure is dependent on density of water ρ, standard gravity g and the height of water level h. The height is calculated by adding all the distances recorded from the bottom of the Erlenmeyer flask to the surface of the water. The density of water was assumed to be constant and $1.00 \times 10^3 kgm^{-3}$. The uncertainties presented in the tables in this investigation have all been calculated using the same procedure as before, calculating it from two extremes and dividing.

The atmospheric pressure has been calculated by recording the atmospheric pressure 5 days in a row and hence finding the average value. The maximum deviation from the average became the uncertainty.

| Geyser number | Height ±0.005m | Density ($kg/m^{-3}$) | Pressure ±49Pa | Average atmospheric pressure ±1200Pa | Total Pressure ±1249Pa |
|---|---|---|---|---|---|
| 1 | 1.450 | $1.00 \times 10^3$ | 14210 | 101113 | 115323 |
| 2 | 1.373 | $1.00 \times 10^3$ | 13455 | 101113 | 114568 |
| 3 | 1.175 | $1.00 \times 10^3$ | 11515 | 101113 | 112628 |
| 4 | 1.112 | $1.00 \times 10^3$ | 10898 | 101113 | 112011 |
| 5 | 1.552 | $1.00 \times 10^3$ | 15210 | 101113 | 116323 |
| 6 | 1.450 | $1.00 \times 10^3$ | 14210 | 101113 | 115323 |
| 7 | 1.381 | $1.00 \times 10^3$ | 13534 | 101113 | 114647 |
| 8 | 1.182 | $1.00 \times 10^3$ | 11584 | 101113 | 112697 |
| 9 | 1.117 | $1.00 \times 10^3$ | 10947 | 101113 | 112060 |

**Table 4 – Pressure calculations**

6 Advanced Level Physics p. 105

Formula for pressure influence on boiling point[7]:

$$\ln\left(\frac{P}{P_o}\right) = \frac{\Delta H_{vap}}{R}\left(\frac{1}{T_o} - \frac{1}{T}\right)$$

$P_o$ = standard atmospheric pressure[8] = 101325 Pa

P = pressure (Pa)

$\Delta H_{vap}$= heat of vaporization of water[9] = 40650$Jmol^{-1}$

R = ideal gas constant[10] = 8.314$Jmol^{-1}K^{-1}$

$T_o$= boiling point of water at pressure $P_o$[11] = 373.15K

T = new boiling point at pressure P (K)

The only variable which is unknown is the new boiling point, which we calculate like this:

$$T = \frac{\frac{\Delta H_{vap}}{R}}{\frac{\Delta H_{vap}}{RT_o} - \ln\left(\frac{P}{P_o}\right)}$$

The uncertainties in the following results are calculated by looking at the difference of the temperatures computed using two extreme pressure values and then taking the half.

| **Geyser number** | **Total Pressure ±1249Pa** | **Calculated boiling point ±0.3°C** | **Mean experimental boiling point ±0.4°C** |
|---|---|---|---|
| 1 | 115323 | 103.7 | 103.6 |
| 2 | 114568 | 103.5 | 103.5 |
| 3 | 112628 | 103.0 | 102.5 |
| 4 | 112011 | 102.9 | 102.5 |
| 5 | 116323 | 104.0 | 104.0 |
| 6 | 115323 | 103.7 | 102.8 |
| 7 | 114647 | 103.6 | 102.7 |
| 8 | 112697 | 103.1 | 102.3 |
| 9 | 112060 | 102.9 | 102.1 |

**Table 5 – Comparison of boiling points**

[7] http://www.science.uwaterloo.ca/~cchieh/cact/c123/clausius.html
[8] http://www.engineeringtoolbox.com/pressure-d_587.html
[9] http://www.gordonengland.co.uk/conversion/constants.htm
[10] http://www.mne.psu.edu/cimbala/learning/general/gas_constant.html
[11] http://lamar.colostate.edu/~hillger/temps.htm

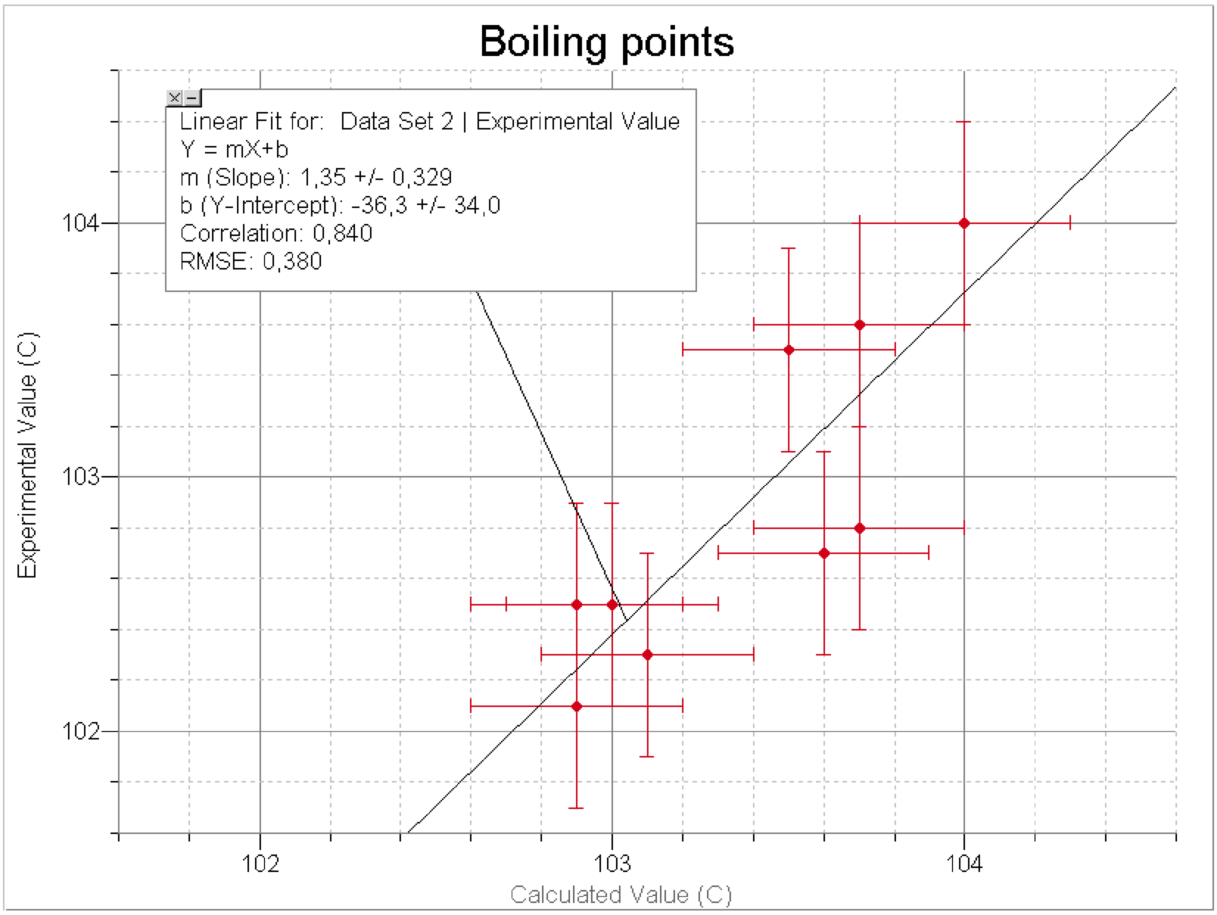


**Figure 11 – A comparison of my experimental boiling points and the calculated values**

In general it appears that when the experimental values divert from the predicted the boiling points are smaller than expected. However all geysers but three match the calculated values if the uncertainties are taken into consideration. The reason for the deviation could be that the model used to calculate the boiling points is not adequate. It does not take into account my generalization of the water density or that the water used could have some chemical agents dissolved in it which could have affected the heat of vaporization.

### 5.7 Summary

We have observed that the temperatures the geysers reach will change with height because of the change in pressure. The path the water has to travel before reaching the surface will affect the nature of the eruption because of potential loss of energy. Most likely some transferred into mechanical energy which made the tube vibrate and some thermal energy was lost to the surroundings during the eruption.

# 6. Varying the amount of water above the tube

In these geysers the amount of water, hence height of water in container is varied.

## 6.1 Primary data collected

| Geyser# | 10 | 9 | 11 |
|---|---|---|---|
| Volume of water | 0.8l | 1.4l | 1.8l |
| Water above stopper±0.001m | 0.010 | 0.029 | 0.050 |
| Eruption height | Very high | High | Very small |
| Eruption width | Broad | Broad | Container |
| Start time of first boil ±0.1seconds | 23:00.9 | 19:39.2 | 23:47.6 |
| Mean boiling temperature ±0.4°C | 102.0 | 102.1 | 102.0 |

**Table 6 – Geysers with different amounts of water in the system**

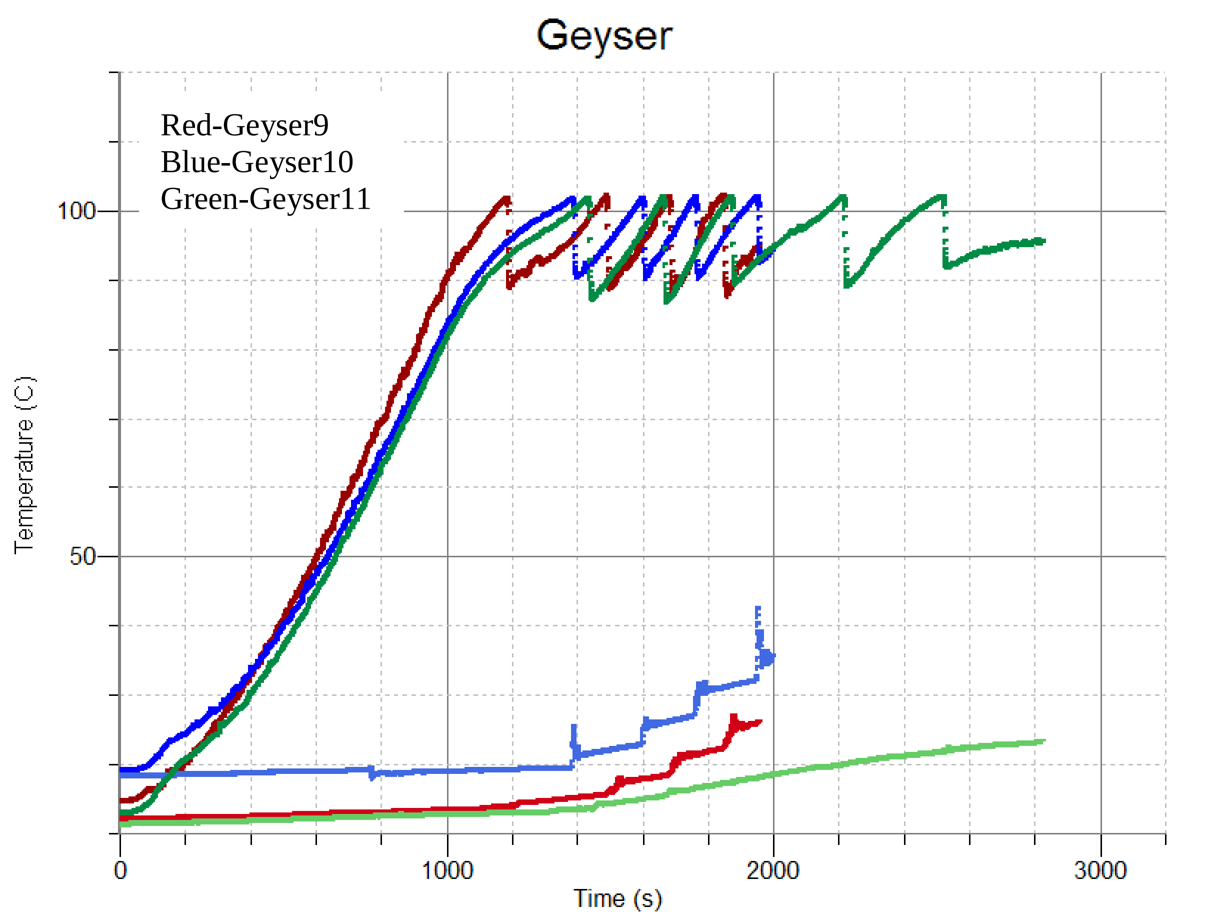


**Figure 12 – A comparison of the geysers with different water volumes**

### 6.2 Analysis of data

The change in height the different amounts of water created was not enough to see a significant change in the highest temperatures as shown in Table 6. However there was an obvious change in the nature of the eruptions. As the water level above the stopper increased the strength of the eruption decreased. The tenth geyser had clearly the largest eruption and is the one where we can observe the highest change in temperature in the container and the most distinct eruptions. In the eleventh geyser, which had the largest amount of water, there was no major eruption, only some bubbling in the container. That would explain the even line, as the hot water simply flowed into the container, mixing with the rest of the water.

### 6.3 Summary

Even though the raised water level increased the pressure the effect was not a more powerful eruption, the positioning of the water made it milder. The eruption was dampened by the water above the tube in the container, it required more energy to reach the water surface and in the most extreme case the result was that water simply flowed into the container instead of erupting.

# 7. Varying the power of heating

By changing the heat setting on the hot plate the geysers got different amounts of power.

## 7.1 Primary data collected

| Geyser# | 9 | 12 | 13 |
|---|---|---|---|
| Heat setting on hotplate | 1 | 2 | 3 |
| Eruption height | High | High | High |
| Eruption width | Broad | Broad | Broad |
| Start time of first boil ±0.1seconds | 19:39.2 | 18:12.3 | 11:35.9 |
| Mean boiling temperature±0.4°C | 102.1 | 102.0 | 102.5 |

**Table 7 – Geysers with different power of heating**

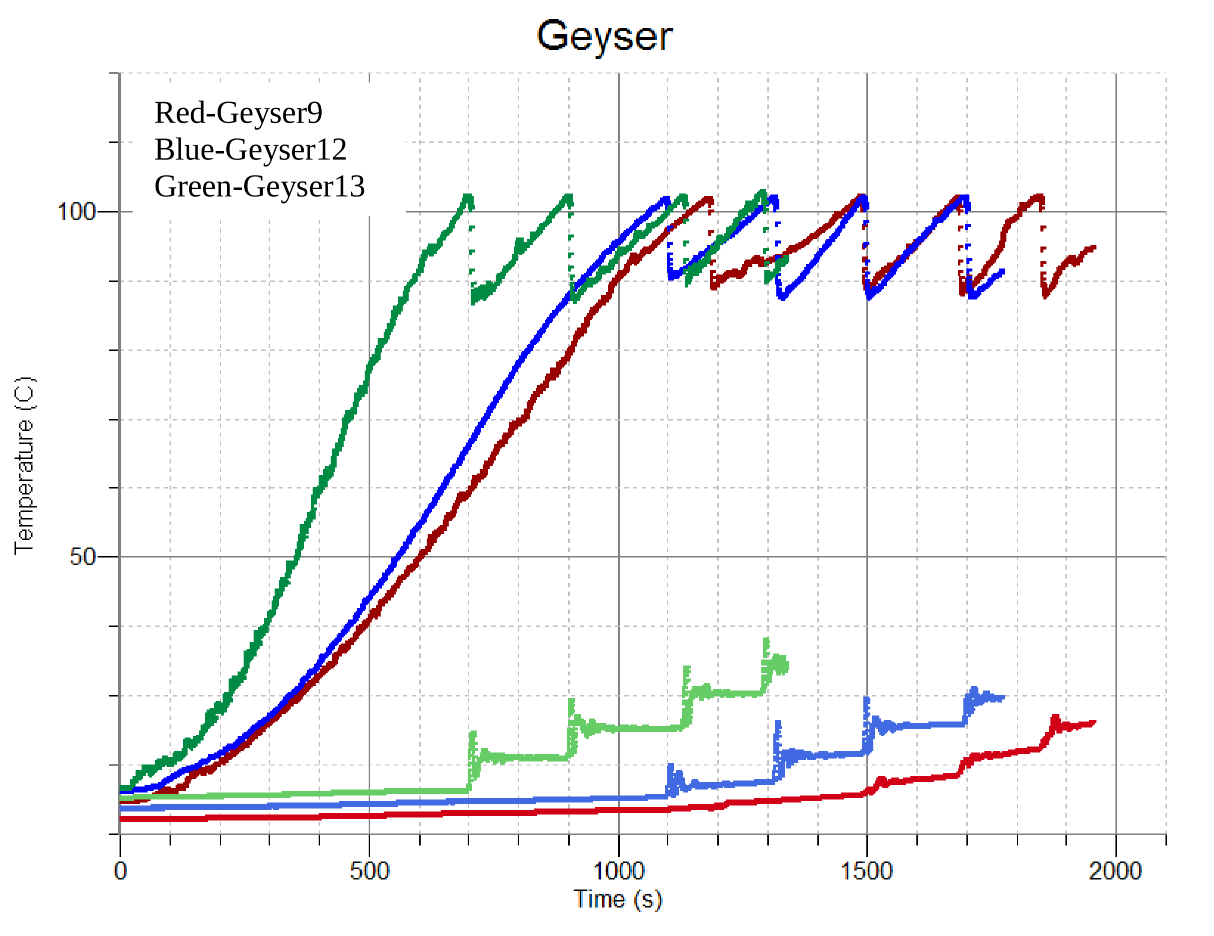


**Figure 13 – A comparison of the geysers with different heating settings**

## 7.2 Analysis of data

Higher power of heating means that the water will boil more quickly, we see this through the initial steepness of the curves. This is only relevant when examining an experimental geyser model as the real geysers is not heating water up from scratch but consists of a stable system. There is a much larger distance between the readings from geyser 13 and the two other geysers, than between geyser 9 and 12. This is due to the difference between the heat settings[12].

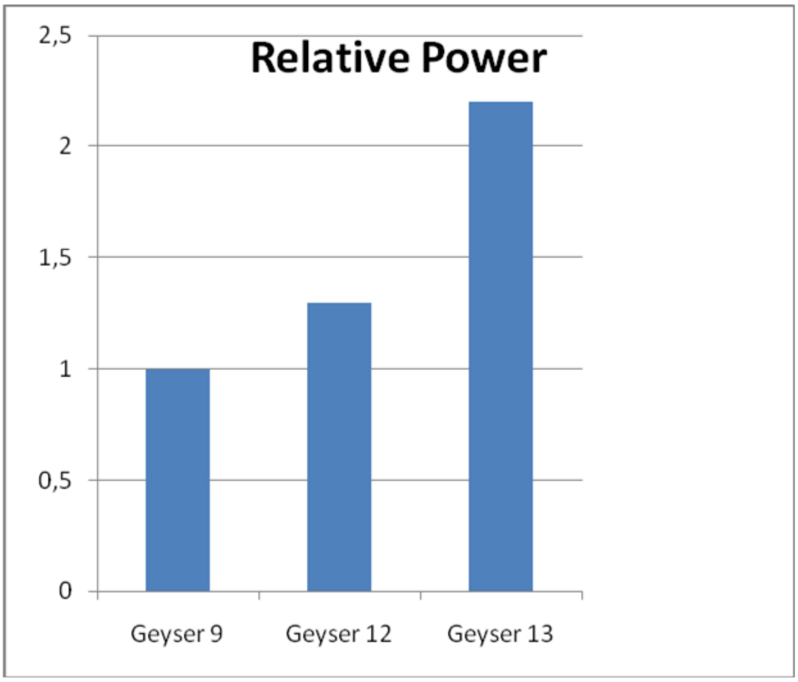


**Figure 65 – The relative difference of the three heat settings**

Another trait is the increasing eruption intensity shown by the changing step formation; this was not recorded in Table 7.

## 7.3 Summary

Even though there were no visible changes in the eruptions the geysers with higher heat setting had larger eruptions, as there were larger and more distinct changes in temperature in those containers. With a more powerful heating source the experimental geyser also erupts quicker.

[12] Calculations in appendix

# 8. Chaos

A similarity between all the geysers, no matter what variable I have changed, has been the irregularity of the eruptions. And so an analysis of the data I have on the eruptions follows.

### 8.1 Intervals between eruptions

In the graphs we can observe how the temperature changes both in the container and flask in the intervals between eruptions. In the flask both the durations of the intervals and heating profile differ. There seems to be no pattern. When we observe randomness in self-oscillatory systems it is caused either by random sources or the appearance of dynamical chaos[13]. Figure 17 shows the intervals between eruptions.

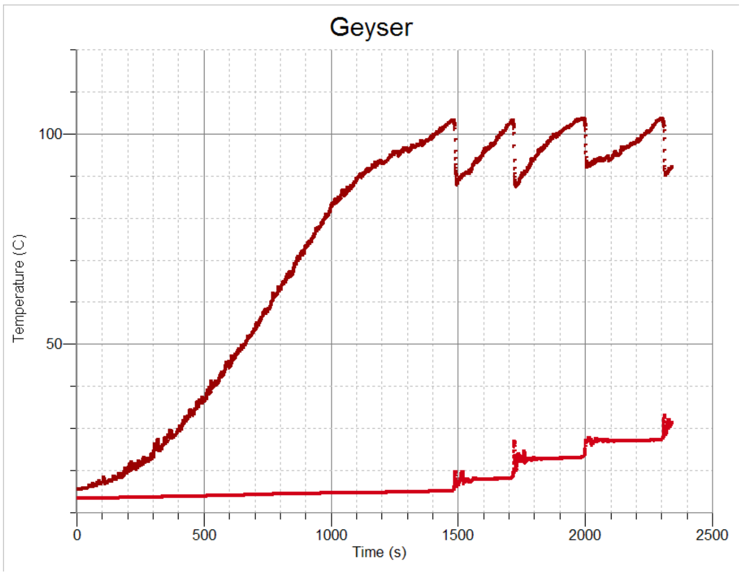


**Figure 16 – Example of a geyser graph**

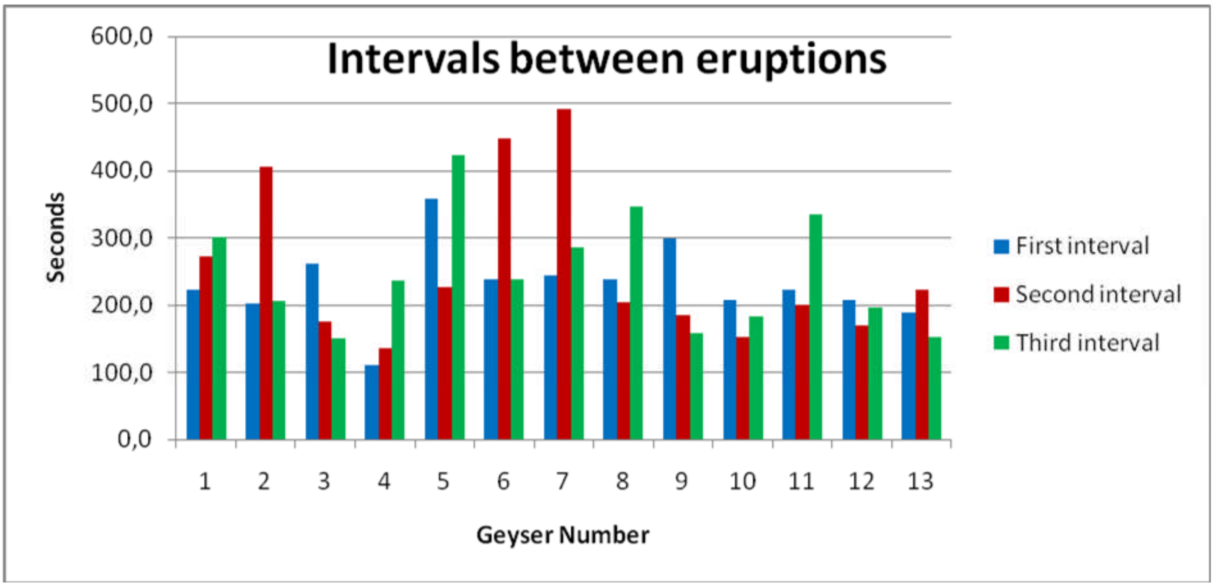


**Figure 17 – The unpredictable durations of intervals**

[13] The Geyser as a self-oscillatory system. Randomness or dynamical chaos?

There seems to be no pattern in which interval is the longest, we find examples of every possibility. Also there do not seem to be any progression showing a general trend going from one geyser to another. This is further shown by comparing the different independent variables with the intervals in Figure 18-20.

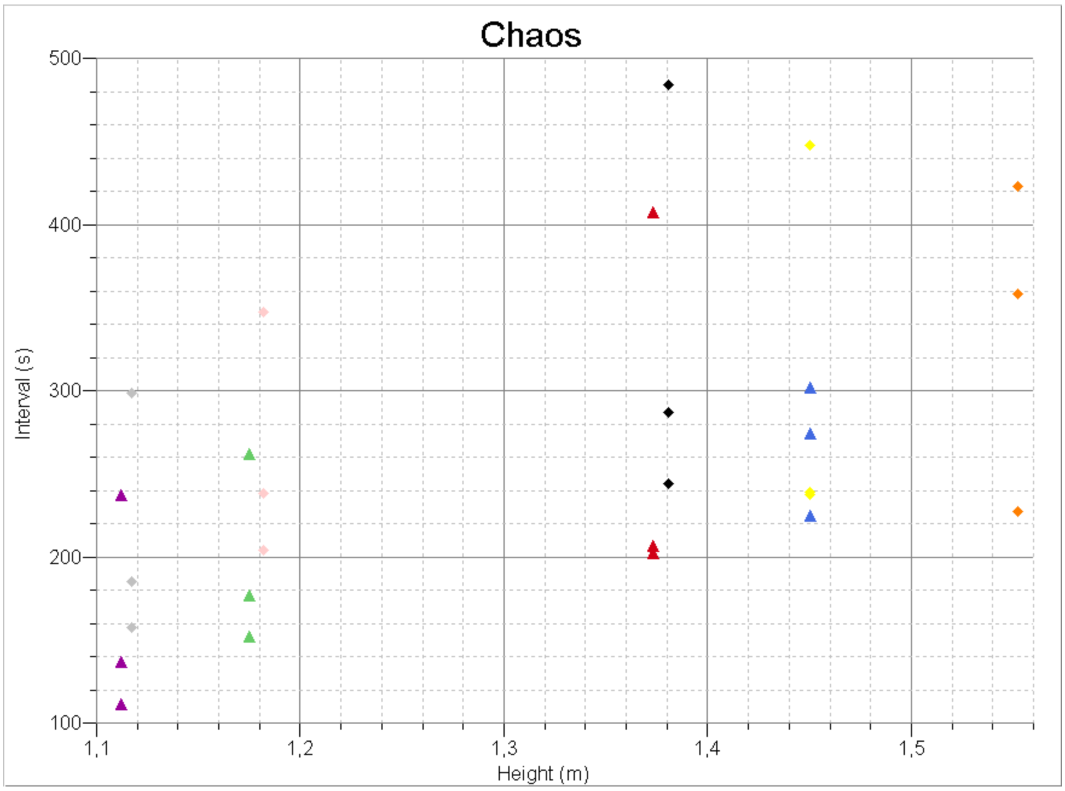


**Figure 18 – A comparison of the intervals between eruptions and the height of the geysers**
**Triangles = geysers with slack tubes, Diamonds = geysers with straight tubes**

In this graph the intervals between the eruptions have been compared with the different heights of geysers. In general it would seem that the ones with slack tubes have shorter intervals. All of the longest intervals occur in the highest geysers and oppositely the shortest intervals appear in the short geysers, but there are also examples of the opposite.

The intervals of the individual geyser are also shown here not to be confined within similar durations. However there seems to be a trait which occur quite often; two short intervals close together and then one which is much longer. This is seen in 7 of 9 geysers. However there is no set pattern for which of the three intervals is the longest and which are the short ones.

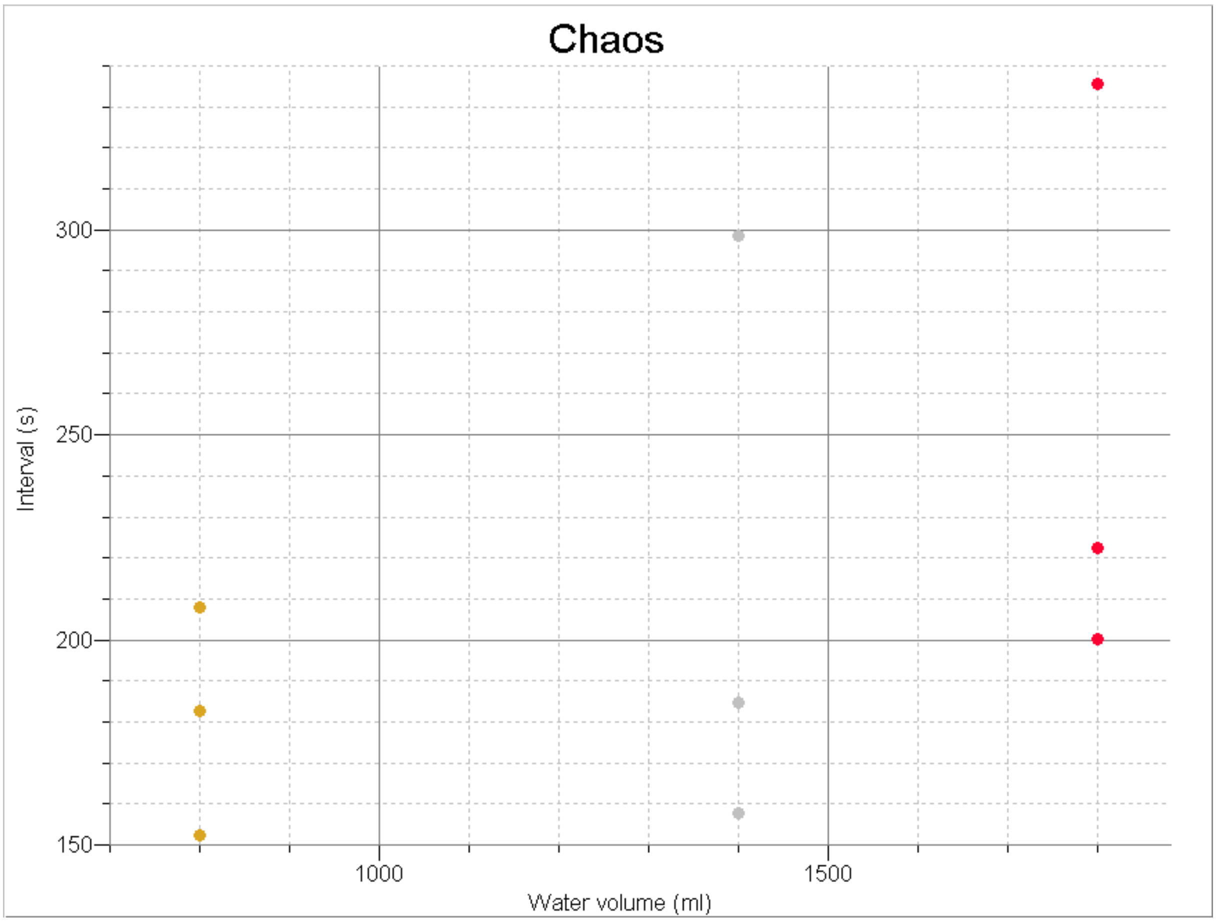


**Figure 19 – A comparison of the intervals between the eruptions of the geysers and the different water volumes**

Here the water volume is compared to the intervals. The geyser with the least water has three intervals which differ with approximately the same amount of time, whilst the two others have the pattern observed frequently in Figure 18. It would appear as though it was not coincidental that the intervals seem to increase with increasing water volume, but this applies only when comparing some of the intervals. Again there are irregularities, where an interval in the geyser with the least water is longer than one in the geyser with the most water.

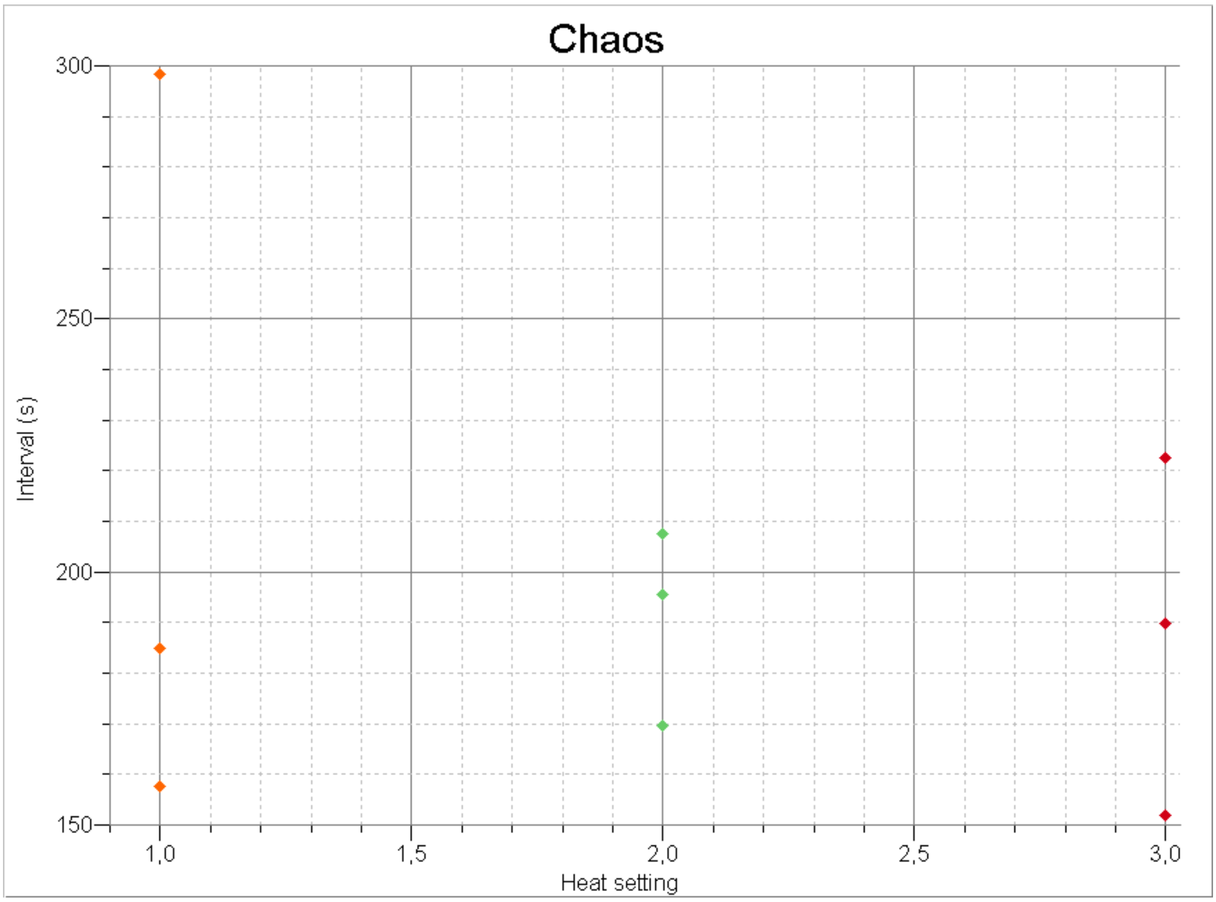


**Figure 20 – A comparison of the intervals between eruptions of geysers and the heating settings**

One could imagine the heating would have an impact on the intervals as the geyser with the highest heat setting finished four cycles much faster than the other two, but still we find examples of shorter intervals in both the geysers with lower heating.

The high interval we find when the heating is low, can be because it takes longer until the geyser is ready to erupt. And perhaps the short intervals could be explained by the fact that it was previously shown that less heat meant smaller eruptions which means that we do not get as much cool water down in the flask. Hence we need less time to get ready for another eruption.

Still I have no explanation as to why the intervals between eruptions vary so much both within an individual geyser and the apparent unpredictability when they are compared. The irregularity leads to an apparent chaotic system.

## 8.2 Duration of eruptions

Another irregularity is the durations of the eruptions, shown in Figure 21.

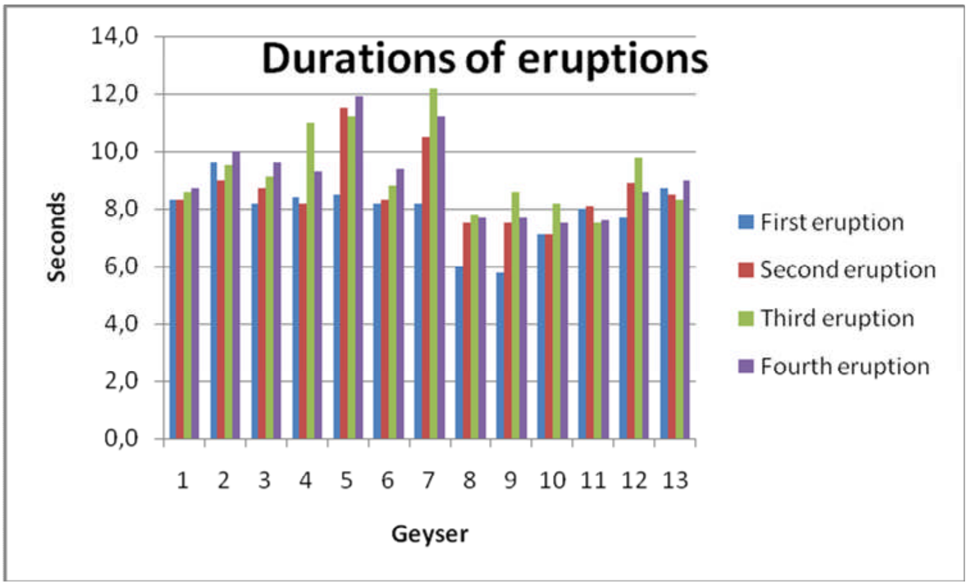


**Figure 21 – the unpredictable durations of eruptions**

In this case at least the values are not so wide spread and the eruptions are quite similar. However there is no pattern in which eruption is largest or which geysers have the longest eruptions. It has differed with a maximum of about four seconds.

A theory of mine was that the duration of the eruptions perhaps was connected to the duration of the interval which followed until the next eruption. By plotting the durations of the eruptions on the y-axis and the durations of the intervals between eruptions on the x-axis however there did not seem to be any correlation.

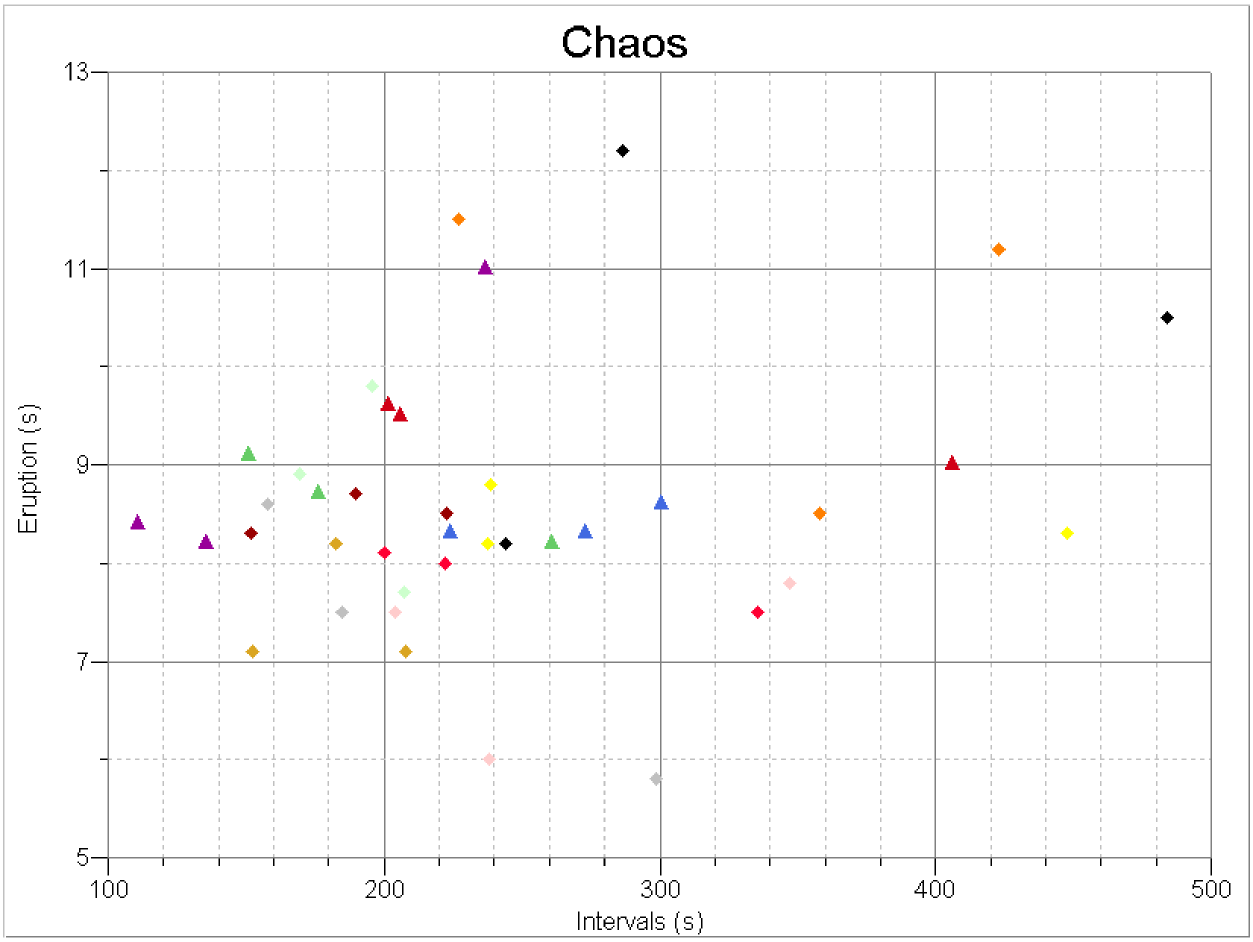


**Figure 22 – A comparison of the intervals between eruptions and the duration of the preceding eruption**

A research paper published in 2008 by scientists P. Landa and D. Vlasov deals with the same issue of chaos in geysers as presented in this essay. They claim the chaotic nature of the geyser is due to a random source induced by the boiling process[14].

## 8.3 Summary

The eruptions still remain a mystery because even though some trends might be indicated there is no overall pattern and no way for me to predict the duration of any interval. It can indicate that my geyser is an example of deterministic chaos where some properties are unpredictable. I cannot say conclusively however because my geyser models did not get the chance to reach a stable state, and so the chaotic behavior could in theory be temporary. However based on the report by Landa and Vlasov it is a trait real geysers have as well caused by the boiling process.

[14] The Geyser as a self-oscillatory system. Randomness or dynamical chaos?

# 9. Evaluation of the model

## 9.1 Limitations

The limitations in this investigation would be aspects of my experimental geyser-model which would potentially ruin the likeness to a geyser. A problem with the investigation would definitely be the heat capacity of the materials involved. It would not be the same as for a real geyser which is surrounded by rocks and earth, as my geyser is built from glass and plastic. The shape of my system will also just be an approximation to real geysers. Another factor was that the geyser-model was filled with cold water which had to be heated up. The real geysers are very old and have stabilized a long time ago; consequently the water is already hot. My geysers did not have decades to stabilize but ran approximately half an hour, at that point the temperature in the top container was still increasing. How the geysers would have worked, after an entire hour is unknown. Another point to consider is the fact that I did not manage to create an equal starting point for every geyser and the water had different temperatures when I turned on the heat. This would affect the appearance of the graphs.

Another limitation would be the small range of the independent variables due to lack of equipment, space, and naturally because of safety precautions. The investigation would probably have been improved with a larger range of variables, and a better way of evaluating my visual observations, such as the height and width of the eruptions. One solution would have been to film the eruptions with a background showing different heights. That way another aspect of the geyser could have been evaluated as well instead of simply stating the relative terms of high and low.

## 9.2 A comparison to natural geysers

The principles of natural geysers are quite similar to those of my experimental geyser-model, as one can tell from the definition of a geyser. There are many types of geysers and they all have individual characteristics, as I proved with my experimental models. The aspects which affect real geyser's characteristics are how much water they contain, how hot the water is, the size and shape of the plumbing system and its connections with other geysers[15]. I have managed to investigate all of these aspects except for the relationship between geysers which

[15] Geysers – What They Are and How They Work p.6

would have proved difficult. I have come to the conclusion that my experimental geyser-model can be compared to the fountain-type geyser[16]. It has open craters at the surface which fills with water, and this water seems to weaken the eruptions when comparing to other geysers. The steam in this type of geyser causes several splashes which creates a bursting and spraying eruption.

## 10.Conclusion

Through this essay I have achieved a better understanding of one of nature's wonders; the geyser. I developed an experimental geyser-model which was able to reproduce properties of real geysers. Changing the pressure, power supply and amount of water would change the maximum temperature reached, the shape of the geysers and the power of each eruption. However, the eruptions were still not predictable and did not form a pattern where the intervals are concerned. But geysers are known to be irregular[17], perhaps therein lays the fascination. Our knowledge of nature is still limited, and there are still many things to discover, if we only take the time to look for it.

[16] Geysers – What They Are and How They Work p.34
[17] Geysers – When Earth Roars p.14

## 11. Sources

**Books:**

Bryan, Scott, (2005), *Geysers – What They Are and How They Work*, 2nd edition, Mountain Press Publishing Company, Montana

Gallant, Roy, (1997), *Geysers – When Earth Roars*, 1st edition, Franklin Watts A Division of Grolier Publishing, The United States of America

Nelkon&Parker, (1997), Advanced Level Physics 7th Edition, Heinemann, Great Britain

Tsokos, K.A,(2008) Physics for the IB Diploma, 5th edition, Cambridge University Press, Great Britain

**Research papers:**

Landa P., Vlasov D., (2008), The geyser as a self-oscillatory system. Randomness or dynamical chaos?, http://journals.pepublishing.com/content/x874u181wt302416/, [19.10.10]

**Web pages:**

http://www.engineeringtoolbox.com/pressure-d_587.html [19.10.10]

http://www.gordonengland.co.uk/conversion/constants.htm [19.10.10]

http://lamar.colostate.edu/~hillger/temps.htm [19.10.10]

http://www.mne.psu.edu/cimbala/learning/general/gas_constant.html [19.10.10]

http://www.science.uwaterloo.ca/~cchieh/cact/c123/clausius.html [19.10.10]

http://www.engineeringtoolbox.com/water-thermal-properties-d_162.html [08.12.10]

## 12. Appendix

**Power calculations**

By looking at the rate of heating in each geyser it is possible to calculate the power of each setting on the hot plate. The formula required is as follows[18]:

$$P = \frac{Q}{t} = \frac{m \times c \times \Delta T}{\Delta t}$$

m = the mass of the water (kg)

c = special heat capacity of water[19] = $4.19 Jkg^{-1}{}^{o}C^{-1}$

$\Delta T$ = change in temperature ($^{o}C$)

$\Delta t$ = change in time (s)

Assumptions:

- I will disregard the fact that I have a large system of water and simply focus on the content of the Erlenmeyer flask.
- I will assume that the temperature recorded by the probe in the flask is equal throughout the flask.
- The density of water is assumed to be $1.00 \times 10^3$ $kgm^{-3}$.

The mass of water in the flask was decided by filling it to the brim putting in the stopper and hence pouring the water still inside into a measuring beaker. The result was 352ml, with an uncertainty of 1ml due to the measuring beaker. As 1ml will equal $1cm^3$ the mass of water in the flask will be 0.352kg. To make the calculations more accurate I used the same two temperatures for all geysers and looked at how long it took each of the geysers to get from one temperature to the other. I chose numbers from late in the process so that I can assume the hot plate has reached a steady power rate. There will of course be an error margin of $0.1^{o}C$ as the temperature probe did not measure more accurately, but the time interval will be approximately from $80.1^{o}C$ to $100.1^{o}C$. This means a change in temperature of $20.0 \pm 0.2^{o}C$.

[18] Physics for the IB diploma p.419
[19] http://www.engineeringtoolbox.com/water-thermal-properties-d_162.html

| Geyser# | Time interval ±1s | Calculations | Relative power | Uncertainty in power |
|---|---|---|---|---|
| 9 | 365 | $\frac{0.352 \times 4.19 \times (20 \pm 0.2)}{365 \pm 1}$ | 0.081 | 0.002 |
| 12 | 270 | $\frac{0.352 \times 4.19 \times (20 \pm 0.2)}{270 \pm 1}$ | 0.109 | 0.001 |
| 13 | 164 | $\frac{0.352 \times 4.19 \times (20 \pm 0.2)}{164 \pm 1}$ | 0.180 | 0.003 |

**Relative power calculations**

Approximate relationship between the three power strengths:

$$Heat\ setting\ 1: \frac{0.081}{0.081} = \mathbf{1.0}$$

$$Heat\ setting\ 2: \frac{0.109}{0.081} \approx \mathbf{1.3}$$

$$Heat\ setting\ 3: \frac{0.180}{0.081} \approx \mathbf{2.2}$$