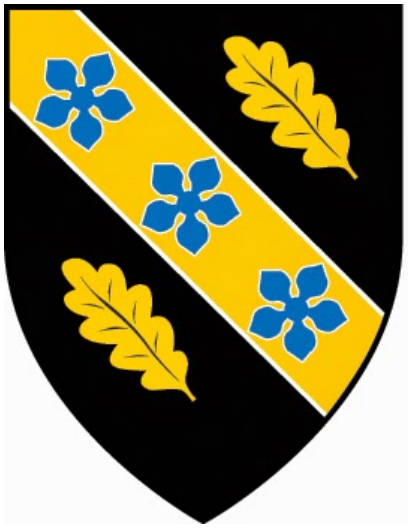


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Structural Integrity and Material Evaluation

Thermography – Newton's Cooling Law

M7X01384

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MSc Mechanical Engineering

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Abstract

This experimental report outlines a lab experiment carried out to investigate heat loss between and open and a closed container filled with hot water using a thermography camera and software. The camera was set up and measured the temperature of both the open and closed container over a time period of 10 minutes, where the temperature of each container was recorded and documented every 30 seconds. The results from the experiment highlighted that the open container had a greater rate of heat loss and overall total amount of heat loss compared to the closed container. This showed that the open container had a greater cooling constant and therefore had a greater accumulated total heat loss as well as mass lost, resulting in the open container subsequently having a greater amount of heat energy lost through the evaporation process.

1.0 Apparatus

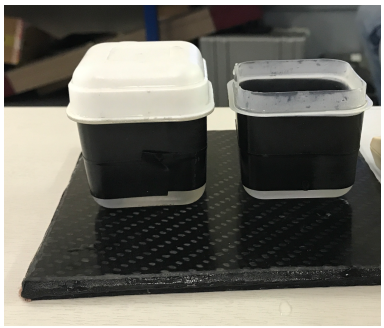


Figure 1.1- Two Plastic containers surrounded with black tape, one with a lid and one without a lid

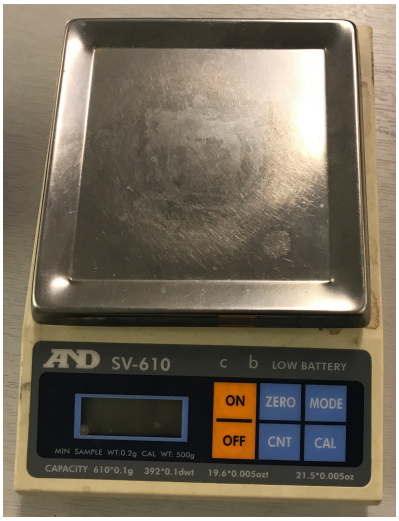


Figure 1.2 – AND SV-610 Weighing Scale

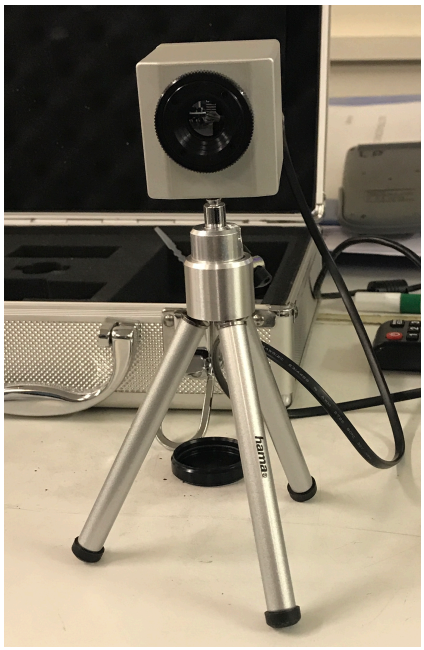


Figure 1.3 Micro-Epsilon Thermal Camera and TIM Software

The equipment was set up in the Lab. The camera was placed on a table and the containers with warm water placed approximately 1.5m away from the camera. Due to issues with the software the thermal camera software did not record all the data therefor the camera was used to measure the temperature at 30s time intervals and the results were manually recorded.

2.0 Introduction

The experiment involved measuring the temperature loss from two systems. The two systems were plastic containers wrapped in black tape as shown in figure 1.1. The two containers are subjected to the same external conditions such as room temperature. However, the one key difference to be noted is one container has a lid whereas the second container has no lid. The experiment involved measuring the change in temperature over a ten-minute time period. The data obtained was then used to determine the following;

- Cooling constant for both the open and the closed container
- Estimate the accumulated heat loss over the duration of the experiment
- The implication on the temperature measured and the estimated heat loss if the emissivity of the container was incorrectly defined
- Estimate the heat energy lost through the evaporation process
- Identify different heat transfer methods that contribute to the total heat loss during the experiment

2.1 Method

Two plastic containers of the same size covered in the same black tape were weighed using the AND SV-610 Weighing Scale shown in figure 1.2 and the weight of the empty containers recorded. The Micro-Epsilon Thermal Camera and TIM Software were set up so that the thermal camera showed the room temperature and the temperature value recorded.

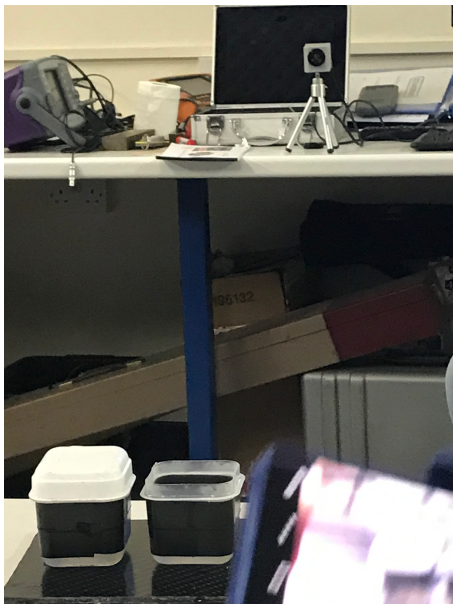


Figure 2.1.1 – Camera and samples set up.

The camera was places approximately 1.5m away from the containers as shown in figure 2.1.1 so a clear image of the bodies could be achieved on the software. Once the camera was clearly positioned the two containers were filled with hot water at the same time from the same water source and the weight of the containers with the water was recorded. The containers were then put into place and the initial temperature of both containers was recorded along with the ambient temperature of the room. All of the temperature data was obtained using the TIM software.

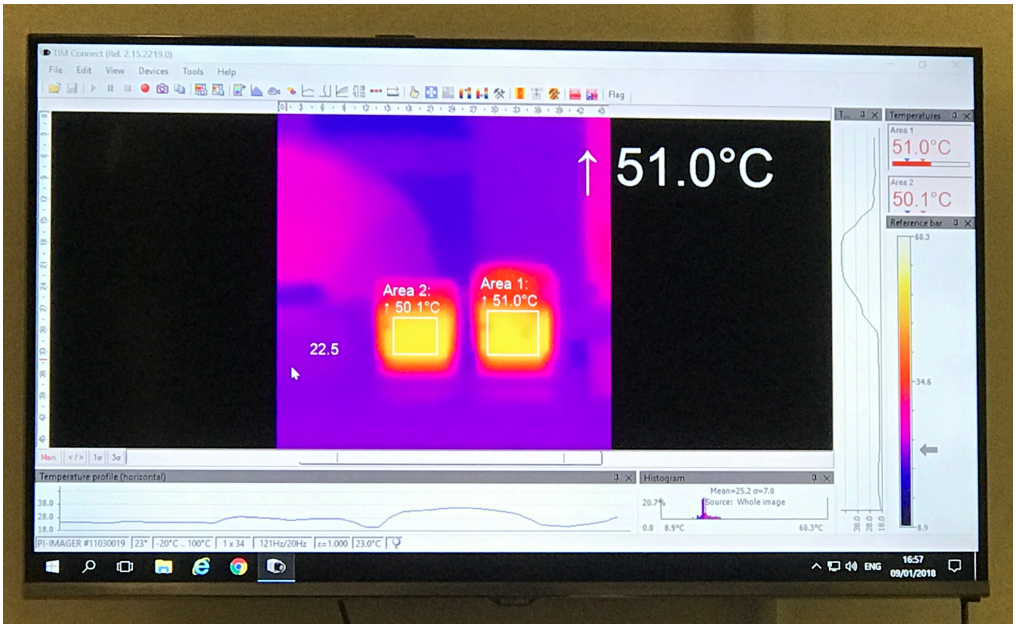


Figure 2.1.2 – TIM Software Highlighting the Temperature of the Open and Closed Containers

Once in position the temperature of both the open and the closed container was recorded every 30 seconds for a duration of 10 minutes in a table. Using the TIM software shown in figure 2.1.2 the temperature values shown on each of the containers every 30s were the values taken and recorded. At the end of the experiment both the open and the closed container were weighed again and the weight recorded.

During the experiment, the following issues which were observed;

1 – the software was not recording all of the data correctly, in order to overcome this issue, the temperature measurements were manually obtained and recorded in a table. Although the problem could be overcome using this method the results noted down could be slightly out and the time the temperature measurements were taken could be slightly out due to human error of reading the temperature seconds after the specified time which could have an impact on the temperature recorded.

2 – As the containers were filled with water in another area of the room and one container had to be filled seconds after the other before being transferred over to the experimental area heat loss would have already began, this would be more prominent for the open container. Therefore, the initial temperature of the containers does vary and will be realised in the results.

3.0 Measurements and Graphs of Raw Measurements

As stated in the methodology a series of measurements were taken as shown in table 3.1

Room Temperature /°C	20
Open empty container weight/g	14.2
Closed empty container weight/g	22.3
Open full container weight/g	108.1
Closed full container weight/g	116.3

Table 3.0.1 – Initial Temperature and Weight Measurements Prior to Experiment

The temperature of both the open and closed container can be seen in Table 3.0.1

	Open Container	**Closed Container**
Time/s	**Temperature/°C**	**Temperature/°C**
0	57.4	60.8
30	56	60
60	55.6	59.7
90	54.9	59.4
120	54	58.7
150	53.7	58.5
180	53	58
210	52.6	57.6
240	52	57.3
270	51.5	56.8
300	51.1	56.4
330	50.7	56.1
360	50.2	55.7
390	49.6	55.2
420	49.1	54.7
450	48.6	54.4
480	48.2	54.1
510	47.8	53.7
540	47.3	53.3
570	46.8	52.9
600	46.5	52.5

Table 3.0.1 – Temperature Measurements for Open and Closed Container at 30s Intervals

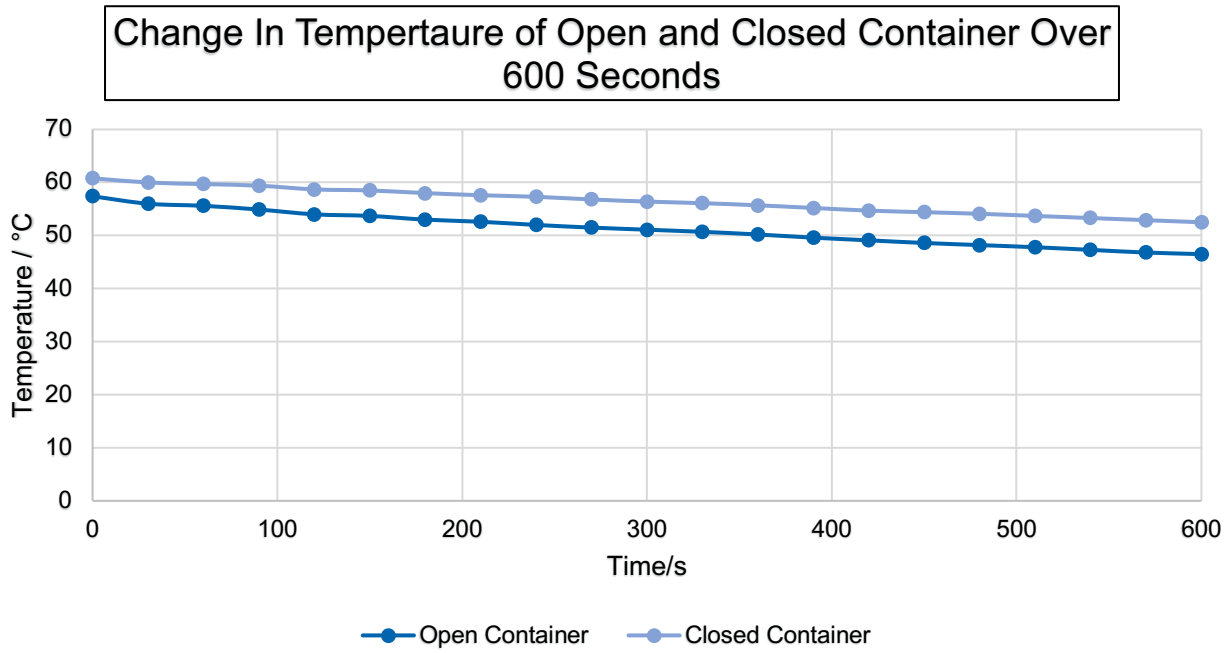


Figure 3.0.1 – Temperature Change of Open and Closed Container Over a 600s Time Period

As shown in Figure 3.0.1 the open container saw a greater loss in temperature over time compared to the closed container.

It has to be taken into consideration that the open container and the closed container were filled with the water a few seconds after each other and then transported to the test area, the containers were then weighted before being put into place and the experiment began. During this time, the open container and the closed container would already be experiencing heat loss due to conduction, convection radiation and evaporation. Therefore, once the experiment had been started it can be seen that the temperature of the open container was lower than that of the closed container.

4.0 Calculations, Error Estimations, Results and Discussion

The following calculations and results were conducted using the data obtained from the experiment.

4.1 From the values obtained, attempt to determine a cooling constant, k.

Based on Newton's cooling law:

$$\frac{\delta T}{\delta t} = -K(T - T_{amb}) \qquad (Equation\ 4.1.1)$$

The cooling constant -K can be calculated by re-arranging Newton's cooling law to:

$$\frac{\left(\frac{\delta T}{\delta t}\right)}{(T - T_{amb})} = -K \qquad (Equation\ 4.1.2)$$

K is a negative value as the temperature is cooling down.

Before the experiment was conducted, the room temperature was taken. The weight of the empty containers as well as the weight of the containers once filled with the water. The data can be found it table 4.1.1

Room Temperature /°C	20
Open empty container weight/g	14.2
Closed empty container weight/g	22.3
Open full container weight/g	108.1
Closed full container weight/g	116.3
Open full container weight/g at end of experiment	107
Closed full container weight/g at end of experiment	116.2

Table 4.1.1 – Initial Temperature and Weight measurements prior to experiment

Open Container

Open Container					
Time/s	**Temperature/°C**	**Δ Temperature/°C**	**(Δ Temperature)/(Δ Time)**	**Temperature - Room Temperature**	**-k**
0	57.4	-	-	-	-
30	56	1.4	0.047	36.0	0.00130
60	55.6	0.4	0.013	35.6	0.00037
90	54.9	0.7	0.023	34.9	0.00067
120	54	0.9	0.030	34.0	0.00088
150	53.7	0.3	0.010	33.7	0.00030
180	53	0.7	0.023	33.0	0.00071
210	52.6	0.4	0.013	32.6	0.00041
240	52	0.6	0.020	32.0	0.00063
270	51.5	0.5	0.017	31.5	0.00053
300	51.1	0.4	0.013	31.1	0.00043
330	50.7	0.4	0.013	30.7	0.00043
360	50.2	0.5	0.017	30.2	0.00055
390	49.6	0.6	0.020	29.6	0.00068
420	49.1	0.5	0.017	29.1	0.00057
450	48.6	0.5	0.017	28.6	0.00058
480	48.2	0.4	0.013	28.2	0.00047
510	47.8	0.4	0.013	27.8	0.00048
540	47.3	0.5	0.017	27.3	0.00061
570	46.8	0.5	0.017	26.8	0.00062
600	46.5	0.3	0.010	26.5	0.00038
				Average -K	**0.00058**

Table 4.1.2 – Open Container Cooling Constant K Calculations

Based on the data obtained for the open container the standard deviation in temperature can be calculated. As stated by Gravetter and Wallnau standard deviation measures the standard distance from the mean. (Gravetter & Wallnau, 2014). This provides an indication of how tightly the values in the dataset are gathered together (University of Surry, 2018).

It can be seen that the mean value of Δ Temperature = 0.008 °C
Therefore, the Standard deviation for the Δ Temperature of the open container is 0.248 °C
Based on the experimental data collected in table 4.1.2 the cooling constant (-k) for the open container is 0.00058 s^{-1}

Closed Container

Closed Container					
Time/s	**Temperature/°C**	**Δ Temperature/°C**	**(Δ Temperature)/(Δ Time)**	**Temperature - Room Temperature**	**-k**
0	60.8	-	-	-	-
30	60	0.8	0.027	40	0.00067
60	59.7	0.3	0.010	39.7	0.00025
90	59.4	0.3	0.010	39.4	0.00025
120	58.7	0.7	0.023	38.7	0.00060
150	58.5	0.2	0.007	38.5	0.00017
180	58	0.5	0.017	38	0.00044
210	57.6	0.4	0.013	37.6	0.00035
240	57.3	0.3	0.010	37.3	0.00027
270	56.8	0.5	0.017	36.8	0.00045
300	56.4	0.4	0.013	36.4	0.00037
330	56.1	0.3	0.010	36.1	0.00028
360	55.7	0.4	0.013	35.7	0.00037
390	55.2	0.5	0.017	35.2	0.00047
420	54.7	0.5	0.017	34.7	0.00048
450	54.4	0.3	0.010	34.4	0.00029
480	54.1	0.3	0.010	34.1	0.00029
510	53.7	0.4	0.013	33.7	0.00040
540	53.3	0.4	0.013	33.3	0.00040
570	52.9	0.4	0.013	32.9	0.00041
600	52.5	0.4	0.013	32.5	0.00041
				Average -K	**0.00038**

Table 4.1.3 – Closed Container Cooling Constant K Calculations

It can be seen that the mean value of Δ Temperature = 0.005 °C

Therefore, the Standard deviation for the Δ Temperature of the open container is 0.142°C

Based on the experimental data collected in table 4.1.3 the cooling constant (-k) for the closed container is 0.00038 s^{-1}

Overall it can be seen that the open container had a greater cooling constant than the closed container, this result was predicted as the open container will be subject to evaporation and mass loss.

Although it was predicted that the open container would have a greater cooling constant than the closed container the value obtained could be incorrect. This could be due to the human error highlighted earlier where the values of temperature were manually being recorded and may have been taken a few seconds too early or late resulting in the incorrect temperature value being obtained. Furthermore, as both the open and the closed container were subject to some heat loss before any data began being recorded could have had an effect on the values obtained.

4.2 Calculate the unit's K would be given in

Based on the re-arrangement of Newton's cooling Law to make the cooling constant K the value the units of k can be calculated by the following;

$$\frac{\left(\frac{\delta T}{\delta t}\right)}{(T - T_{amb})} = -K \qquad Equation\ 4.2.1$$

Based on the base units it can be seen that K is;

$$\frac{\left(\frac{\mathbf{^\circ C}}{s}\right)}{(\mathbf{^\circ C} - \mathbf{^\circ C})} = -K \qquad Equation\ 4.2.2$$

$$\frac{\left(\frac{\mathbf{^\circ C}}{s}\right)}{(\mathbf{^\circ C})} = -K \qquad Equation\ 4.2.3$$

Based on the units in equation 4.2.3 it can be seen that the units of k would be s^{-1}

4.3 Estimate the accumulated total heat loss over the duration of the experiment

Open Container

$$Q_{lost} = m.C_p.\Delta T \qquad Equation\ 4.3.1$$

Cp = 4180 J/kg. °C

m = Average mass = 0.107Kg

ΔT = Total temperature change = 10.9°C

$$m = \frac{Start\ mass + End\ Mass}{2} \qquad Equation\ 4.3.2$$

$$m = \frac{108.1 + 107}{2} = 107.55g = 0.107Kg$$

$$Q_{lost} = (0.107).(4180).(10.9) \qquad Equation\ 4.3.3$$

$$Q_{lost} = 5875.13\ J$$

Closed Container

$$Q_{lost} = m.C_p.\Delta T \qquad Equation\ 4.3.1$$

Cp = 4180 J/kg. °C

m = Average mass = 0.116Kg

ΔT = Total temperature change = 8.3°C

$$m = \frac{Start\ mass + End\ Mass}{2} \qquad Equation\ 4.3.2$$

$$m = \frac{116.3 + 116.2}{2} = 0.116Kg$$

$$Q_{lost} = (0.116).(4180).(8.3) \qquad Equation\ 4.3.3$$

$$Q_{lost} = 4024.50\,J$$

It can be seen from equation 4.3.3 that the accumulated total heat loss over the duration of the experiment was greater for the open container than for the closed container. The open container would experience a greater total heal loss over the duration as the container was subjected to evaporation allowing the liquid to escape and result in not only a mass loss but subsequently a greater heat loss from the system. Although the closed container did experience heat loss, the heat loss was less than that of the open container as there was no mass loss due to evaporation as the lid prevented any matter from leaving the system. Evaporation would be observed however the evaporated material would hit the roof of the lid and condense resulting in no mass loss to the system.

4.4 Assuming the container surface behaves like a grey body and utilising your experimentally derived emissivity value for the container, estimate the monochromatic total radiation intensity for each observed temperature value.

Assuming the containers surface behaves like a grey body the emissivity of the container is estimated to be 0.95. Based on equation 4.4.1 an estimation of the total radiation intensity for each temperature value can be calculated.

$$w = \varepsilon . \Delta . T^4 \qquad Equation\ 4.4.1$$

$w = Intensity$

$\varepsilon = Emissivity = 0.95$

$\Delta = Stefan\ Boltzmann\ Constant = 5.67\ W/m^2K^4$

$T = Temperature$

Open Container					
Stefan Boltzmann Constant (W/cm^2.K4)	**Emissivity**	**Temperature/°C**	**Temperature/K**	**T^4/K**	**W/(W/cm^2)**
5.67E-12	0.95	57.4	330.4	11916813829	0.0642
5.67E-12	0.95	56	329	11716114081	0.0631
5.67E-12	0.95	55.6	328.6	11659239846	0.0628
5.67E-12	0.95	54.9	327.9	11560208489	0.0623
5.67E-12	0.95	54	327	11433811041	0.0616
5.67E-12	0.95	53.7	326.7	11391909808	0.0614
5.67E-12	0.95	53	326	11294588176	0.0608
5.67E-12	0.95	52.6	325.6	11239256556	0.0605
5.67E-12	0.95	52	325	11156640625	0.0601
5.67E-12	0.95	51.5	324.5	11088142650	0.0597
5.67E-12	0.95	51.1	324.1	11033571765	0.0594
5.67E-12	0.95	50.7	323.7	10979202559	0.0591
5.67E-12	0.95	50.2	323.2	10911523904	0.0588
5.67E-12	0.95	49.6	322.6	10830723087	0.0583
5.67E-12	0.95	49.1	322.1	10763732578	0.0580
5.67E-12	0.95	48.6	321.6	10697053313	0.0576
5.67E-12	0.95	48.2	321.2	10643933350	0.0573
5.67E-12	0.95	47.8	320.8	10591011472	0.0570
5.67E-12	0.95	47.3	320.3	10525136931	0.0567
5.67E-12	0.95	46.8	319.8	10459570166	0.0563
5.67E-12	0.95	46.5	319.5	10420377440	0.0561

Figure 4.4.1 – Total radiation intensity for each observed temperature value in the open container

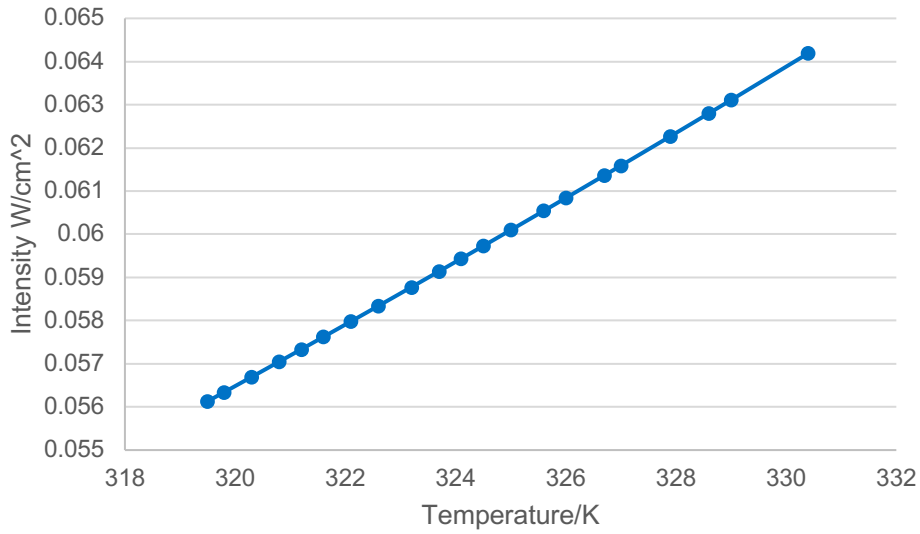


Figure 4.4.2 – Total radiation intensity for each observed temperature value in the open container

Closed Container					
Stefan Boltzmann Constant (W/cm^2.K4)	**Emissivity**	**Temperature/°C**	**Temperature/K**	**T^4/K**	**w/(W/cm^2)**
5.67E-12	0.95	60.8	333.8	12414960136	0.0669
5.67E-12	0.95	60	333	12296370321	0.0662
5.67E-12	0.95	59.7	332.7	12252118921	0.0660
5.67E-12	0.95	59.4	332.4	12207987065	0.0658
5.67E-12	0.95	58.7	331.7	12105476420	0.0652
5.67E-12	0.95	58.5	331.5	12076306610	0.0650
5.67E-12	0.95	58	331	12003612721	0.0647
5.67E-12	0.95	57.6	330.6	11945694309	0.0643
5.67E-12	0.95	57.3	330.3	11902393242	0.0641
5.67E-12	0.95	56.8	329.8	11830486525	0.0637
5.67E-12	0.95	56.4	329.4	11773196139	0.0634
5.67E-12	0.95	56.1	329.1	11730365092	0.0632
5.67E-12	0.95	55.7	328.7	11673438949	0.0629
5.67E-12	0.95	55.2	328.2	11602572928	0.0625
5.67E-12	0.95	54.7	327.7	11532030054	0.0621
5.67E-12	0.95	54.4	327.4	11489859029	0.0619
5.67E-12	0.95	54.1	327.1	11447803771	0.0617
5.67E-12	0.95	53.7	326.7	11391909808	0.0614
5.67E-12	0.95	53.3	326.3	11336220771	0.0611
5.67E-12	0.95	52.9	325.9	11280736161	0.0608
5.67E-12	0.95	52.5	325.5	11225455475	0.0605

Figure 4.4.3 – Total radiation intensity for each observed temperature value in the closed container

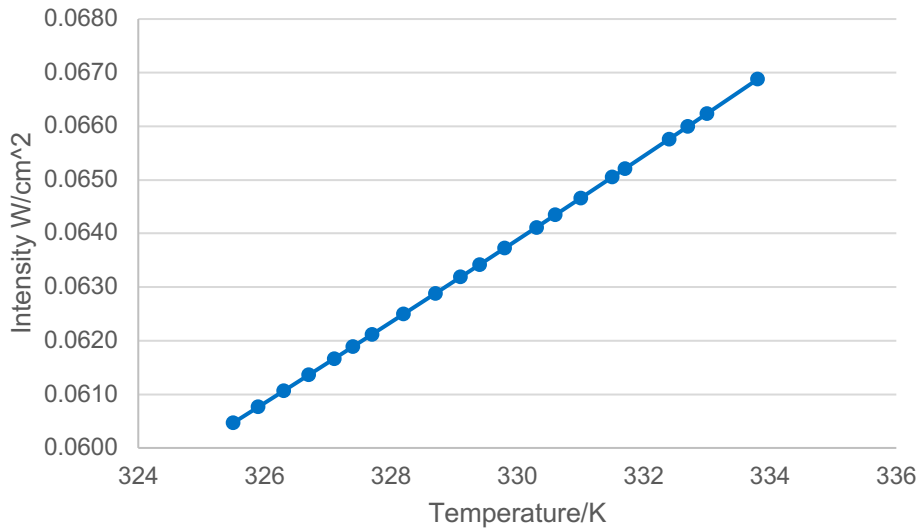


Figure 4.4.4 – Total radiation intensity for each observed temperature value in the closed container

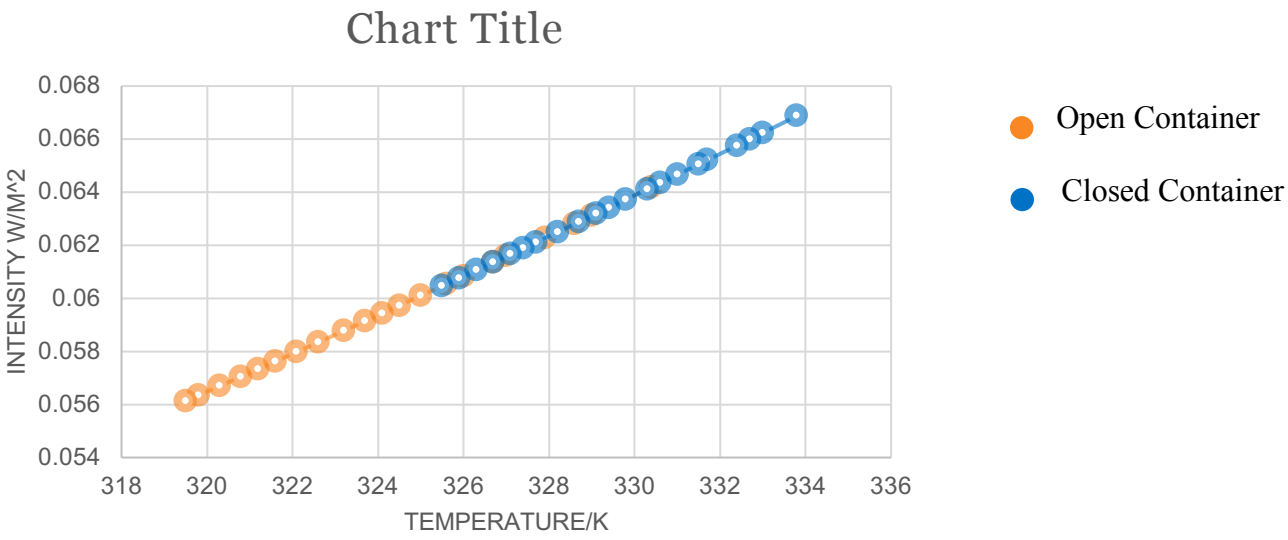


Figure 4.4.5 – Total radiation intensity for each observed temperature value in the pen and closed container

On comparison, it can be seen that the closed container had greater radiation intensity for each temperature value. This is a result of the closed container having greater temperature values in general. Based on equation 4.4.1 as the emissivity value and the Stefan Boltzmann Constant do not change the greater the value of temperature the greater the value of intensity will be.

4.5 If the emissivity of the container surface had been incorrectly defined what implications would this have had on the temperature measurements and estimated heat loss

Emissivity is defined by the dictionary as the ability of a surface to emit radiant energy compared to that of a black body which is subject to the same conditions (Oxford English Dictionary, 2017). The emissivity of a black body has an emissivity factor of 1 (Twigg, 2012). This means all other bodies can have an emissivity factor of between 0 and 1 but only black bodies will have an emissivity factor of 1.

If the emissivity of the container surface was incorrectly defined and the value was significantly higher than the actual value, an incorrect reading will be obtained. By the emissivity value being significantly higher than the actual, the result will be an underestimation in the temperature value. This has been further specified by Ippolito & Cigola and the Temperature and Process Instruments Inc. who state that if the value of emissivity used is higher than the actual value and the temperature of the object is greater than the environmental temperature, the temperature measured by the camera will be lower than the physical one. Furthermore, as stated by Ippolito & Cigola the lower the emissivity value the greater the error will be (Temperature and Process Instruments Inc.) (Ippolito & Cigola, 2017).

4.6 Using the observed water mass loss, provide an estimate of the heat energy lost through the evaporation process over the duration of the experiment.

$Q_{evap=m.L}$ *Equation* 4.6.1

Q= Heat Energy Lost through evaporation

m = Mass Lost

L = Latent Heat

Open Container

$Q_{evap=m.L}$

Weight of empty open container = 14.2g

Weight of full open container at start of experiment = 108.1g

Weight of full open container at end of experiment = 107g

Mass Lost (m) = (108.1-14.2) -(107-14.2) *Equation 4.6.2*

Mass Lost (m) = 93.9-92.8

Mass Lost (m) = 1.1g

$Q_{evap=m.L}$

$Q_{evap=(1.1x10^{-3}).(2260)}$

$Q_{evap=2.486\ KJ}$

For the open container, it can be seen that the estimated amount of heat energy lost throughout the experiment due to evaporation is 2.486 KJ

Closed Container

$Q_{evap=m.L}$

Weight of empty closed container = 22.3g

Weight of full closed container at start of experiment = 116.3g

Weight of full closed container at end of experiment = 116.2g

Mass Lost (m) = (116.3-22.3) -(116.2-22.3) *Equation 4.6.3*

Mass Lost (m) = 94-93.9

Mass Lost (m) = 0.1g

$Q_{evap=m.L}$

$Q_{evap=(0.1x10^{-3}).(2260)}$

$Q_{evap=0.226\ KJ}$

For the closed container, it can be seen that the estimated amount of heat energy lost throughout the experiment due to evaporation is 0.226 KJ

On Comparison of results it can be seen that the open container has a greater estimated amount of heat energy loss. This is due to the open container being subjected to numerous heat transfer methods.

4.7 Comment on the other heat transfer methods that contribute to the total heat loss during the experiment

As stated by Srinivansa in the Principles of Heat Transfer and Roland, Lewis, Nithiarasu, & Seetharamu in the Fundamentals of the Finite Element Method for Heat and Fluid Flow, heat transfer can be accomplished by Conduction, Convection, Radiation and Evaporation (Srinivasan, 2003) (Roland, Lewis, Nithiarasu, & Seetharamu, 2004).

Conduction

Conduction is a mode of heat transfer where heat exchange takes place in solids or quiescent fluids. The heat is transferred from a region of high temperature into a region of low temperature, this is a result of molecules colliding. (Chemistry Dictionary, 2015) (Hahn & Necati Ã–zisik, 2012).

Convection

Convection heat transfer is observed when heat is transferred by the mass movement of molecules from one place to another as stated by the Chemistry Dictionary. Convection therefor involves the transport of heat from one point to another in a fluid as a result of macroscopic motions of the fluid (Raju, 2011).

Evaporation

It is the process whereby atoms or molecules in a liquid state gain sufficient energy to enter the gaseous state. As Stated by Science Daily and the Chemistry Dictionary, the thermal motion of the molecule must be sufficient enough to overcome surface tension and therefor evaporate. In order for this to happen the kinetic energy must be greater than the work function of cohesion. (Science Daily, 2017) (Chemistry Dictionary, 2015).

In the case of the experiment the open container was subjected to Conduction, Convection, Radiation and Evaporation.

Heat was lost through conduction where the heat of the liquid was transferred to the cool outer part of the container, the heat was then lost through thermal radiation.

Heat was also lost through convection which involves the movement of the liquid molecules within the container. Convection of the water molecules involves the hot molecules located in the centre of the liquid start to move towards the outer part of the container where heat will subsequently be lost.

The final heat transfer method that would be observed in the open container is evaporation. The Liquid changes from a liquid state into a gaseous sate and escapes into the atmosphere. Resulting in energy being lost as well as mass which results in heat loss from the system.

The closed container will also experience conduction convection, radiation and evaporation. However, due to the closed container having a lid any liquid which does evaporate will hit the lid of the closed container and will condense, the liquid will then travel back down the container and re-join the liquid in the container so there will be no mass loss within the system. Resulting in a lower energy and heat loss compared to the open container.

5.0 Conclusion

Overall it can be seen from all the results that the open container experienced a faster rate of heat loss than that of the closed container. The prediction for the experiment is that the open container would experience a greater heat loss than the closed container due to there being no lid on the container. The results of the experiment prove that the initial hypothesis was correct as the open container did experience a greater amount of heat loss. This is due to a number of reasons.

1- As the open container did not have a lid, therefor the liquid was subject to evaporation. Evaporation of the liquid resulted in a loss of mass allowing the open system to cool faster than the closed system. The closed system was not subject to mass loss due to the lid on the container.

2- As well as being subject to evaporation both systems were also subjected to heat loss due to conduction and convection.

Due to the Open container experiencing mass loss due to evaporation as well as being subjected to Conduction, Convection and Radiation the open container therefore had a greater cooling constant of 0.00058 s-1 compared to the closed container with a cooling constant of 0.00038 s-1 The greater the cooling constant is an indication that the open container is losing more heat than the closed container.

Improvement for the experiment

If the experiment was to be conducted again a few improvements that should be considered are;

1- Have both containers in position in front of the thermography camera and fill the containers simultaneously so that there is very little time between filling the containers and the first reading being taken. Therefore, very little heat loss would be observed as there is no time delay between filling the containers and taking the first temperature reading.

2- The containers could potentially be placed on a weighing scale each for the duration of the experiment so that weight measurements could be taken immediately once the containers are filled with the water and there is no delay between taking the weight measurement of one container then removing that container from the scale and weighing the second container. During this time, some heat may already be lost due to evaporation in the case of the open container so to try and improve the accuracy of the weight measurement being taken, keeping both containers on scales for the duration will allow measurements to be taken at a faster rate with little time delay.

3- A key improvement would be to have the software of the camera fully functioning so that accurate reading could be taken from both of the containers, as they were manually obtained for the current experiment the readings may not be accurate due to human error of taking the result a few seconds before or after the specified time.

4- To improve the experiment and obtained more accurate and detailed data the experiment could be carried out over a longer time period and taking results more often allowing a more detailed graph to be plotted.

6.0– References

Chemistry Dictionary. (2015). *Evaporation*. Retrieved January 21, 2018, from Chemistry Dictionary: http://www.chemistry-dictionary.com/definition/evaporation.php

Gravetter, F. J., & Wallnau, L. B. (2014). *Essentials of Statistics for the Behavioral Sciences* (8th Edition ed.).

Hahn, D. W., & Necati Ã–zisik, M. (2012). *Heat Conduction* (3rd Edition ed.). John Wiley & Sons.

Ippolito, A., & Cigola, M. (2017). *Handbook of Research on Emerging Technologies for Digital Preservation and Information Modeling.* IGI Global.

Oxford English Dictionary. (2017). *The Oxford English Dictionary.*

Raju, K. S. (2011). *Fluid Mechanics, Heat Transfer, and Mass Transfer: Chemical Engineering Practice.* John Wiley & Sons.

Roland, W., Lewis, P., Nithiarasu, K., & Seetharamu, N. (2004). *Fundamenals of the Finite Element Method for Heat and Fluid Flow.* John Wiley and Sons.

Science Daily. (2017). Evaportaion.

Srinivasan, D. (2003). *Principles of Heat Transfer.* New Age International.

Temperature and Process Instruments Inc. (n.d.). *Technical Information Data Bulletin.*

Twigg, P. (2012). *Science for Motor Vehicle Engineers.* Butterworth Heinemann.

University of Surry. (2018). *Numeracy Skills*. Retrieved from University of Surry: http://libweb.surrey.ac.uk/library/skills/Number%20Skills%20Leicester/index.htm

7.0- Appendix

Open Container					
Time/s	Temperature/°C	Δ Temperature/°C	(Δ Temperature)/(Δ Time)	Temperature -Room Temperature	k
0	57.4	-	-	-	-
30	56	=G4-G5	=H5/30	=G5-C3	=I5/J5
60	55.6	=G5-G6	=H6/30	=G6-C3	=I6/J6
90	54.9	=G6-G7	=H7/30	=G7-C3	=I7/J7
120	54	=G7-G8	=H8/30	=G8-C3	=I8/J8
150	53.7	=G8-G9	=H9/30	=G9-C3	=I9/J9
180	53	=G9-G10	=H10/30	=G10-C3	=I10/J10
210	52.6	=G10-G11	=H11/30	=G11-C3	=I11/J11
240	52	=G11-G12	=H12/30	=G12-C3	=I12/J12
270	51.5	=G12-G13	=H13/30	=G13-C3	=I13/J13
300	51.1	=G13-G14	=H14/30	=G14-C3	=I14/J14
330	50.7	=G14-G15	=H15/30	=G15-C3	=I15/J15
360	50.2	=G15-G16	=H16/30	=G16-C3	=I16/J16
390	49.6	=G16-G17	=H17/30	=G17-C3	=I17/J17
420	49.1	=G17-G18	=H18/30	=G18-C3	=I18/J18
450	48.6	=G18-G19	=H19/30	=G19-C3	=I19/J19
480	48.2	=G19-G20	=H20/30	=G20-C3	=I20/J20
510	47.8	=G20-G21	=H21/30	=G21-C3	=I21/J21
540	47.3	=G21-G22	=H22/30	=G22-C3	=I22/J22
570	46.8	=G22-G23	=H23/30	=G23-C3	=I23/J23
600	46.5	=G23-G24	=H24/30	=G24-C3	=I24/J24
				Average K	=(AVERAGE(K5:K24))

Figure 7.0.1 - Open Container Excel sheet Formulas used to calculate cooling constant

Closed Container					
Time/s	Temperature/°C	Δ Temperature/°C	(Δ Temperature)/(Δ Time)	Temperature -Room Temperature	k
0	60.8	-	-	-	-
30	60	=G29-G30	=H30/30	=G30-C3	=I30/J30
60	59.7	=G30-G31	=H31/30	=G31-C3	=I31/J31
90	59.4	=G31-G32	=H32/30	=G32-C3	=I32/J32
120	58.7	=G32-G33	=H33/30	=G33-C3	=I33/J33
150	58.5	=G33-G34	=H34/30	=G34-C3	=I34/J34
180	58	=G34-G35	=H35/30	=G35-C3	=I35/J35
210	57.6	=G35-G36	=H36/30	=G36-C3	=I36/J36
240	57.3	=G36-G37	=H37/30	=G37-C3	=I37/J37
270	56.8	=G37-G38	=H38/30	=G38-C3	=I38/J38
300	56.4	=G38-G39	=H39/30	=G39-C3	=I39/J39
330	56.1	=G39-G40	=H40/30	=G40-C3	=I40/J40
360	55.7	=G40-G41	=H41/30	=G41-C3	=I41/J41
390	55.2	=G41-G42	=H42/30	=G42-C3	=I42/J42
420	54.7	=G42-G43	=H43/30	=G43-C3	=I43/J43
450	54.4	=G43-G44	=H44/30	=G44-C3	=I44/J44
480	54.1	=G44-G45	=H45/30	=G45-C3	=I45/J45
510	53.7	=G45-G46	=H46/30	=G46-C3	=I46/J46
540	53.3	=G46-G47	=H47/30	=G47-C3	=I47/J47
570	52.9	=G47-G48	=H48/30	=G48-C3	=I48/J48
600	52.5	=G48-G49	=H49/30	=G49-C3	=I49/J49
				Average K	=AVERAGE(K30:K49)

Figure 7.0.2 - Closed Container Excel sheet Formulas used to calculate cooling constant

Open Container					
Stefan Boltzmann Constant (W/cm^2.K4)	Emissivity	Temperature/°C	Temperature/K	T^4/K	W/(W/cm^2)
0.00000000000567	0.95	=57.4	=O3+273	=P3^4	=M3*N3*Q3
0.00000000000567	0.95	56	=O4+273	=P4^4	=M4*N4*Q4
0.00000000000567	0.95	55.6	=O5+273	=P5^4	=M5*N5*Q5
0.00000000000567	0.95	54.9	=O6+273	=P6^4	=M6*N6*Q6
0.00000000000567	0.95	54	=O7+273	=P7^4	=M7*N7*Q7
0.00000000000567	0.95	53.7	=O8+273	=P8^4	=M8*N8*Q8
0.00000000000567	0.95	53	=O9+273	=P9^4	=M9*N9*Q9
0.00000000000567	0.95	52.6	=O10+273	=P10^4	=M10*N10*Q10
0.00000000000567	0.95	52	=O11+273	=P11^4	=M11*N11*Q11
0.00000000000567	0.95	51.5	=O12+273	=P12^4	=M12*N12*Q12
0.00000000000567	0.95	51.1	=O13+273	=P13^4	=M13*N13*Q13
0.00000000000567	0.95	50.7	=O14+273	=P14^4	=M14*N14*Q14
0.00000000000567	0.95	50.2	=O15+273	=P15^4	=M15*N15*Q15
0.00000000000567	0.95	49.6	=O16+273	=P16^4	=M16*N16*Q16
0.00000000000567	0.95	49.1	=O17+273	=P17^4	=M17*N17*Q17
0.00000000000567	0.95	48.6	=O18+273	=P18^4	=M18*N18*Q18
0.00000000000567	0.95	48.2	=O19+273	=P19^4	=M19*N19*Q19
0.00000000000567	0.95	47.8	=O20+273	=P20^4	=M20*N20*Q20
0.00000000000567	0.95	47.3	=O21+273	=P21^4	=M21*N21*Q21
0.00000000000567	0.95	46.8	=O22+273	=P22^4	=M22*N22*Q22
0.00000000000567	0.95	46.5	=O23+273	=P23^4	=M23*N23*Q23

Figure 7.0.3 - Open Container Excel sheet Formulas used to calculate Intensity for each temperature value

Closed Container					
Stefan Boltzmann Constant (W/cm^2.K4)	Emissivity	Temperature/°C	Temperature/K	T^4/K	w/(W/cm^2)
0.00000000000567	0.95	60.8	=O27+273	=P27^4	=M27*N27*Q27
0.00000000000567	0.95	60	=O28+273	=P28^4	=M28*N28*Q28
0.00000000000567	0.95	59.7	=O29+273	=P29^4	=M29*N29*Q29
0.00000000000567	0.95	59.4	=O30+273	=P30^4	=M30*N30*Q30
0.00000000000567	0.95	58.7	=O31+273	=P31^4	=M31*N31*Q31
0.00000000000567	0.95	58.5	=O32+273	=P32^4	=M32*N32*Q32
0.00000000000567	0.95	58	=O33+273	=P33^4	=M33*N33*Q33
0.00000000000567	0.95	57.6	=O34+273	=P34^4	=M34*N34*Q34
0.00000000000567	0.95	57.3	=O35+273	=P35^4	=M35*N35*Q35
0.00000000000567	0.95	56.8	=O36+273	=P36^4	=M36*N36*Q36
0.00000000000567	0.95	56.4	=O37+273	=P37^4	=M37*N37*Q37
0.00000000000567	0.95	56.1	=O38+273	=P38^4	=M38*N38*Q38
0.00000000000567	0.95	55.7	=O39+273	=P39^4	=M39*N39*Q39
0.00000000000567	0.95	55.2	=O40+273	=P40^4	=M40*N40*Q40
0.00000000000567	0.95	54.7	=O41+273	=P41^4	=M41*N41*Q41
0.00000000000567	0.95	54.4	=O42+273	=P42^4	=M42*N42*Q42
0.00000000000567	0.95	54.1	=O43+273	=P43^4	=M43*N43*Q43
0.00000000000567	0.95	53.7	=O44+273	=P44^4	=M44*N44*Q44
0.00000000000567	0.95	53.3	=O45+273	=P45^4	=M45*N45*Q45
0.00000000000567	0.95	52.9	=O46+273	=P46^4	=M46*N46*Q46
0.00000000000567	0.95	52.5	=O47+273	=P47^4	=M47*N47*Q47

Figure 7.0.4 - Closed Container Excel sheet Formulas used to calculate Intensity for each temperature value