ASEN 2012 Project 1 Calorimetry

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In this lab, we used data collected from a calorimetry experiment to determine the specific heat of an unknown sample. We also used error propagation techniques to find the error in the calculated specific heat. We then used our calculated specific heat to identify the unknown sample using a given table of candidate materials and their properties. I calculated the specific heat of the unknown sample to be 0.248 ± 0.000268 [J/kg*K]. The calculated value of specific heat most closely matches the specific heat of Tellurium Copper Alloy, with a discrepancy of 0.013 [J/kg*K]. Thus, it was determined that the known sample was most likely Tellurium Copper (Alloy 145).

I. Nomenclature

m_c	=	mass of calorimeter
m_s	=	mass of sample
c_c	=	specific heat capacity of calorimeter
c_s	=	specific heat capacity of sample
T_2	=	equilibrium temperature of calorimeter and sample
T_1	=	initial temperature of sample
T_0	=	initial temperature of calorimeter
ΔU	=	change in internal energy of system
U_2	=	initial internal energy of system
U_1	=	final internal energy of system

II. Introduction

This project uses concepts from calorimetry to find the specific heat of an unknown sample. Calorimetry is defined as a basic technique for measuring thermodynamic properties. In a typical calorimetry experiment, an unknown sample is placed inside a well-insulated container filled with a liquid with known properties. As heat is transferred from the sample to the known liquid, it becomes possible to determine the properties of the sample. With regards to this specific experiment, water was chosen to be the known liquid, and a standard purchased calorimeter was used as the insulated container.

The formula used to calculate the specific heat of the sample is as follows:

$$c_s = \frac{m_c c_c (T_2 - T_0)}{m_s (T_1 - T_2)} \tag{1}$$

With regards to each term in the above equation:
m_c and m_s can be measured by some type of mass balance
c_c should be given by the manufacturer of the calorimeter
T_1 can be obtained from the temperature of the water in which the sample is heated
T_0 can be obtained from the temperature profile of the calorimeter
T_2 can be obtained from the temperature profile of the calorimeter

Note that the because the container used for calorimetry isn't perfectly insulated, it is necessary to use a procedure provided by the manufacturer of the calorimeter that uses the method of least squares fit and extrapolation to better approximate T_2, T_1, and T_0. More specifically, T_0 is approximated by fitting a line to the pre-sample temperature

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collected during the first 10 minutes of the experiment. Then the line is extrapolated forward to the time the sample was added: 11 minutes into the experiment. A second line is then fitted from the maximum temperature reading to the last temperature reading. This line is then extrapolated back to the time when the sample was added: 11 minutes into the experiment. These two extrapolated temperature values are then averaged and the second line of best fit is extrapolated backwards to the time corresponding to this average temperature value. The resulting extrapolated temperature value is T_2, the final temperature of the calorimeter and sample at equilibrium. These new extrapolated approximates for T_0 and T_2 are then plugged into formula derived above for calculating the specific heat of the unknown sample, together with m_c, m_s, c_c, and T_1.

In addition, it is important to note that each of the of the terms present in equation 1 has uncertainty, and that these uncertainties must be propagated using the techniques covered in class in order to find the uncertainty in the calculated specific heat of the sample.

The general error propagation formula was used to calculate the error in the specific heat of the sample. This formula, along with all of the partial derivatives used in it, are listed below.

$$\sigma c_s = \sqrt{(\frac{\partial c_s}{\partial m_c} * \sigma m_c)^2 + (\frac{\partial c_s}{\partial T_2} * \sigma T_2)^2 + (\frac{\partial c_s}{\partial T_1} * \sigma T_1)^2 + (\frac{\partial c_s}{\partial m_s} * \sigma m_s)^2 + (\frac{\partial c_s}{\partial T_0} * \sigma T_0)^2} \tag{2}$$

$$\frac{\partial c_s}{\partial m_c} = \frac{c_c(-T_0 + T_2)}{m_s(T_1 - T_2)} \tag{3}$$

$$\frac{\partial c_s}{\partial T_2} = \frac{c_c m_c}{m_s(T_1 - T2)} + \frac{c_c m_c(-T_0 + T_2)}{m_s(T_1 - T_2)^2} \tag{4}$$

$$\frac{\partial c_s}{\partial T_0} = -\frac{c_c m_c}{m_s(T_1 - T_2)} \tag{5}$$

$$\frac{\partial c_s}{\partial T_1} = -\frac{c_c m_c(-T_0 + T_2)}{m_s(T_1 - T_2)^2} \tag{6}$$

$$\frac{\partial c_s}{\partial m_s} = -\frac{c_c m_c(-T_0 + T_2)}{m_s^2(T_1 - T_2)} \tag{7}$$

III. Experimental Method

1) Examine the calorimeter. Note that the calorimeter is made of aluminum with an exact specific heat of 0.214 cal/(g*C).
2) The sample is weighed multiple times to determine an average mass.
3) A thermocouple with software cold-junction compensation and ITLL LabStations was used to take temperature readings of the aluminum calorimeter.
4) The thermocouple is placed into the hold provided and secured with high temperature cotton before the insulation cap is replaced.
5) The sample is immersed in boiling water for about 10 minutes until is in equilibrium with the boiling water.
6) At the same time, the sample is immersed in the boiling water, the temperature measuring software is initiated. It takes samples every second.
7) The sample is then removed from the boiling water using tongs. It is shaken and then quickly placed inside the calorimeter. The calorimeter is then sealed.
8) The temperature measuring software runs for about 10 minutes before the experiment ends.
9) The program is terminated and the data is saved

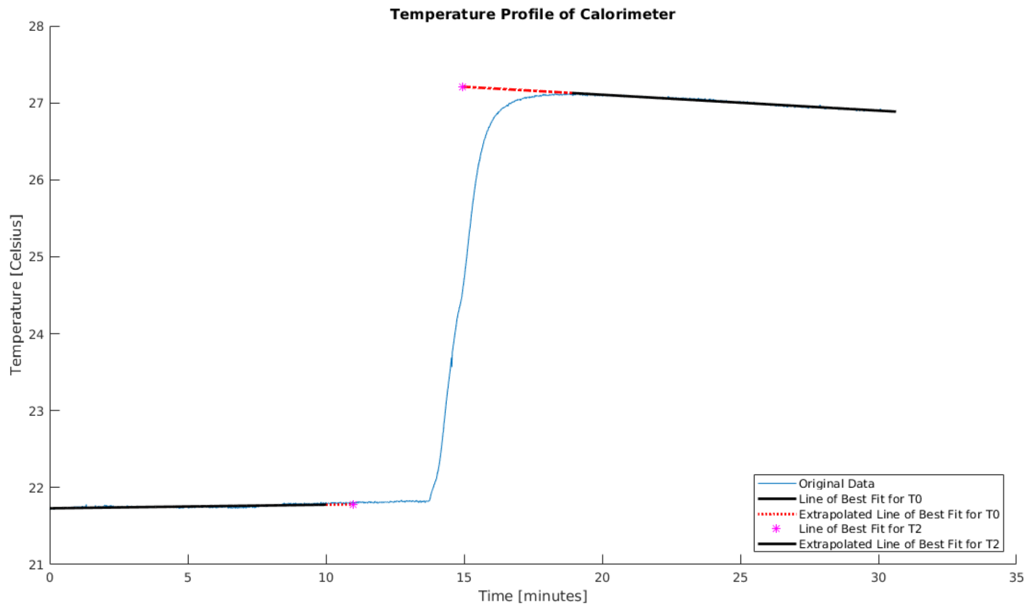

Fig. 1 Temperature Profile of Calorimeter with Least Square Best Fit Lines.

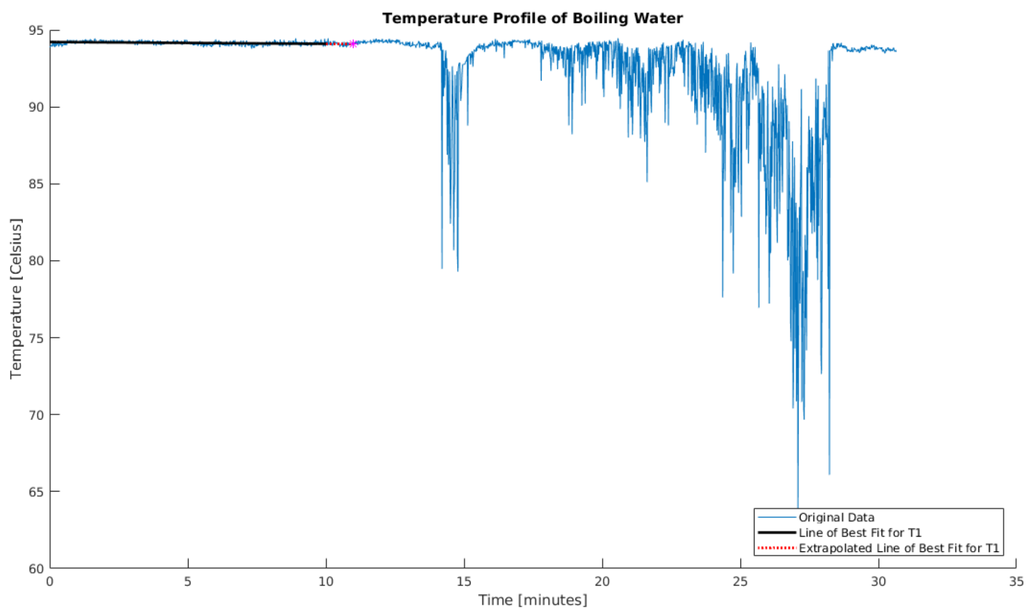

Fig. 2 Temperature Profile of Boiling Water with Least Square Best Fit Lines.

IV. Results

The specific heat of the sample was found to be approximately 0.248 J/gK with an error of approximately 0.000172 J/gK. Comparing this value with the those in the provided table of candidate materials properties shows that while the specific heat of the sample doesn't exactly match up with any of the 4 provided materials, it most closely matches the specific heat of Tellurium Copper (Alloy 145), which has an specific heat of 0.261 J/gK. For a more explicit comparison, consider that the difference between the specific heat of the sample and the Tellurium Copper is a mere 0.013 J/gK. On the other hand, the difference between the specific heat of the sample and Zn (0.402 J/gK), Pb (0.129 J/gK), and Al (0.9 J/gK) is 0.154 J/gK, 0.119 J/gK, and 0.652 J/gK, respectively.

V. Discussion

In this case, the deviation between the measured specific heat of the sample and the specific heat of Tellurium Copper is significant, as the specific heat of Tellurium Copper does not fall within the error bounds of the measured specific heat of the sample. This indicates that the errors of the parameters used in my calculation of the specific heat of the sample need to be larger than they are now. Looking at each of the parameters in equation 1, the errors in the temperature measurements T0, T1, T2 were all calculated using the methods taught in class. Assuming these methods were used properly, the only to obtain a larger error in these values is to increase the range of temperature measurements used to produce the lines of best fit, thereby introducing greater variation between the values. Perhaps a more simple method to increase the error in the calculated specific heat of the sample is to increase the error assigned to the mass of the calorimeter and the sample. This increase in error may be justified if there were human errors made when measuring the mass of the calorimeter or sample. For example, it is possible that the scale used wasn't calibrated properly, or not enough mass measurements were taken before calculating the average mass. Finally, perhaps a more practical justification for the discrepancy between the measured and accepted specific heat is that the method used to approximate the values of T0,T1,T2 is flawed. For example, the measured specific heat would be greater if the difference between T2 and T0 or T1 and T2 increased. That means that if the approximated value of T0 were lower and T1 were higher, the discrepancy between the measured and accepted specific heat values could be reduced. As such, if this experiment were conducted using a more accurate calorimeter with better insulation, we would likely obtain better results.

VI. Conclusion

The identity of the sample is most likely Tellurium Copper (Alloy 145). While the calculated specific heat of the sample does deviate significantly from the accepted specific heat, it was still possible to identify the the sample with a great degree of certainty. This is because the discrepancy between the specific heat of the sample and Tellurium Copper is far lower than the discrepancy between the specific heat of the sample and Zn-Cu-Ti, Pb, or the discrepancy between the specific heat of the sample and 6063-T1 Al. Thus, it is reasonable to deem this experiment a success.

References

Jackson, J., "ASEN 2012 Project 1 Calorimetry," Oct. 2017.
Jackson, J., "Calorimetry Experimental Procedure," Oct. 2017.
Jackson, J., "Calorimetry Additional Data," Oct. 2017.
Jackson, J., "Candidate Materials Properties," Oct. 2017.
Jackson, J., "ASEN 2012 Project 1 Calorimetry," Oct. 2017.

Appendix

The complete derivation of the formula used to calculate the specific of the sample is as follows:

$$\Delta U = 0 \tag{8}$$

$$U_2 - U_1 = 0 \tag{9}$$

$$(m_c u_{c2} + m_s u_{s2}) - (m_c u_{c1} + m_s u_{s1}) = 0 \tag{10}$$

$$m_s c_s (T_1 - T_2) = m_c c_c (T_2 - T_0) \tag{11}$$

$$c_s = \frac{m_c c_c (T_2 - T_0)}{m_s (T_1 - T_2)} \tag{12}$$

Explicit Use of Engineering Method for Algorithm Development

- Problem: I need use the method of least squares and the error propagation formulas learned in class to identify an unknown sample by calculating its specific heat.
- Knowns: Data that contain measurements of the temperature at different times of the calorimeter and boiling water bath. The mass of the sample and of the calorimeter and their uncertainties.
- Find: The specific heat of the sample and its uncertainty using the data provided.
- Assumptions: The mass and uncertainties provided are correct. The sample is added to the calorimeter 10 minutes after the data started to be collected. It is valid to use all error propagation and other techniques covered in class.
- Sketch: See algorithm diagrams below.
- Fundamentals: See equations and other concepts presented in the introduction.
- Alternatives: Could use a better calorimeter, eliminating the need to extrapolate and approximate. Could use a mass spectrometer or other devices to use the metals composition to determine its identity. Could also carry out chemistry experiments or visually compare it with other materials to test its properties and help identify it.
- Steps:
    1) Parse data
    2) Find T0
    3) Find error in T0
    4) Find T2
    5) Find error in T2
    6) Find T1
    7) Find error in T1
    8) Find the specific heat of the sample
    9) Find the error in the specific heat of the sample
    10) Plot the temperature profile and least squares best fit lines for the calorimeter and boiling water
    11) Print findings to output file
- Check: I have verified that my value for the specific heat of the sample and the error in the specific heat of the sample matches that of my peers.
- Makes Sense?: I believe so. There wasn't very much variation in the points used to generate all 3 lines of best fit. In addition, the error in the masses was small. Thus, it makes sense for the error in the specific heat to be small. The calculated value of the specific heat is similar to that of Tellurium Copper, which seems reasonable.

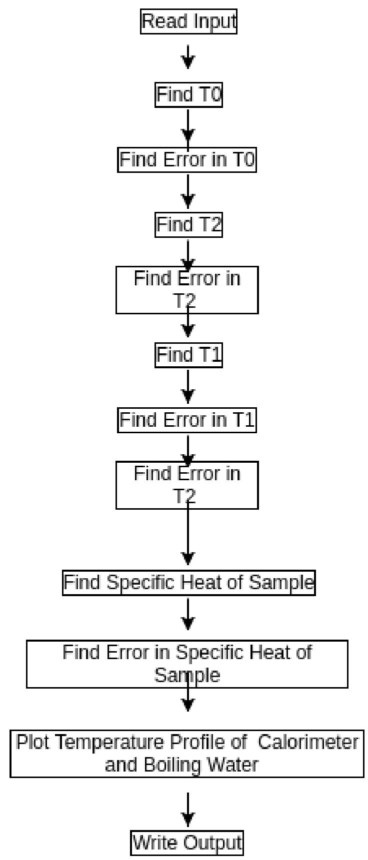

Fig. 3 Main Program Algorithm Flow Chart

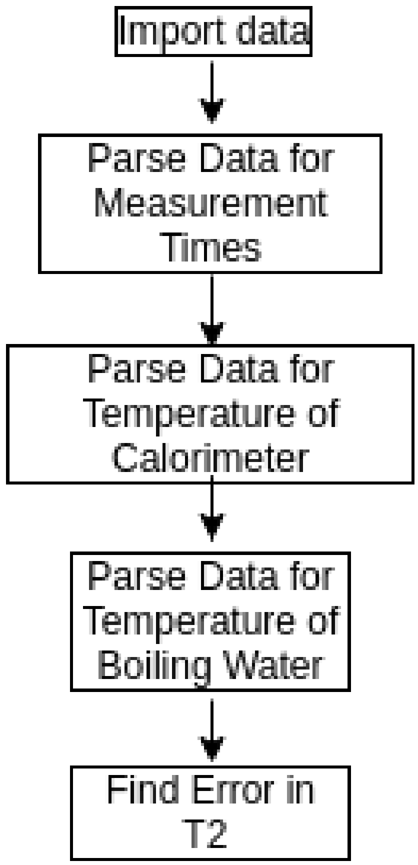

Fig. 4 Subroutine 1: readinput Algorithm Flow Chart

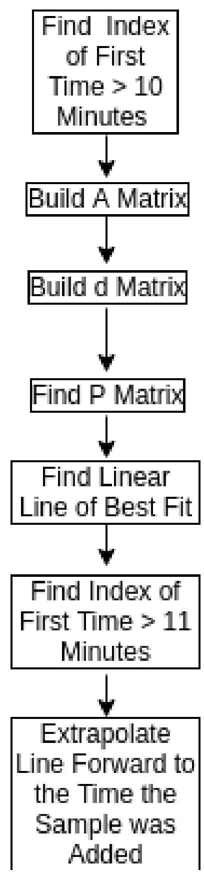

Fig. 5 Subroutine 2: findT0 Algorithm Flow Chart

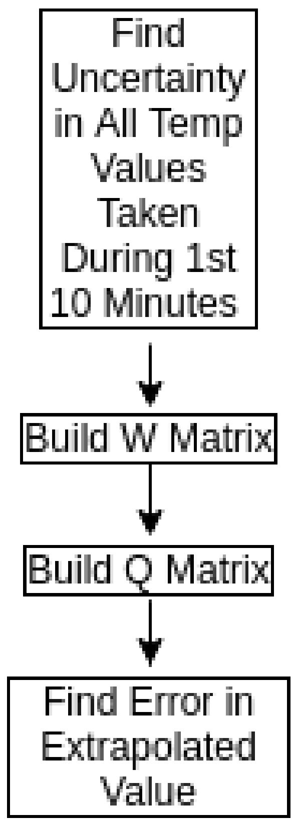

Fig. 6 Subroutine 3: findsigT0 Algorithm Flow Chart

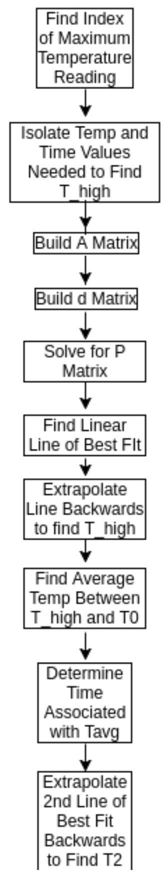

Fig. 7 Subroutine 4: findT2 Algorithm Flow Chart

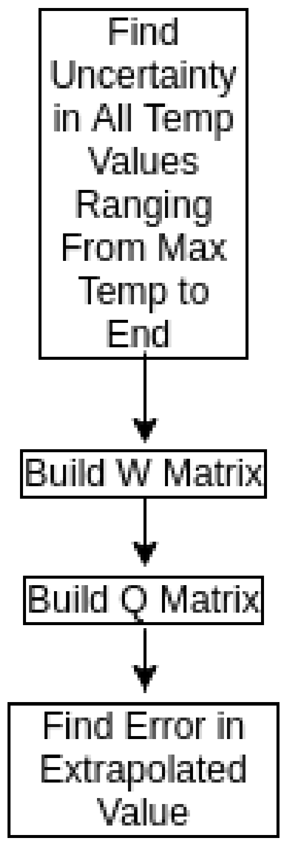

Fig. 8 Subroutine 5: findsigT2 Algorithm Flow Chart

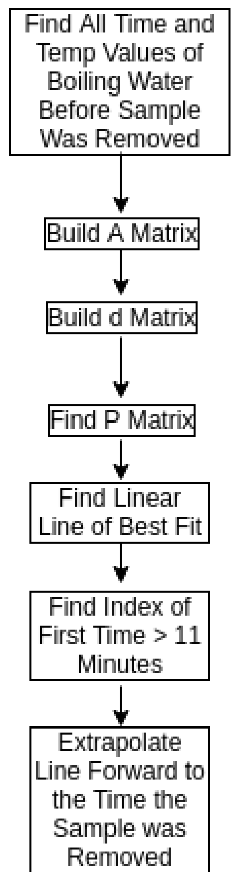

Fig. 9 Subroutine 6: findT2 Algorithm Flow Chart

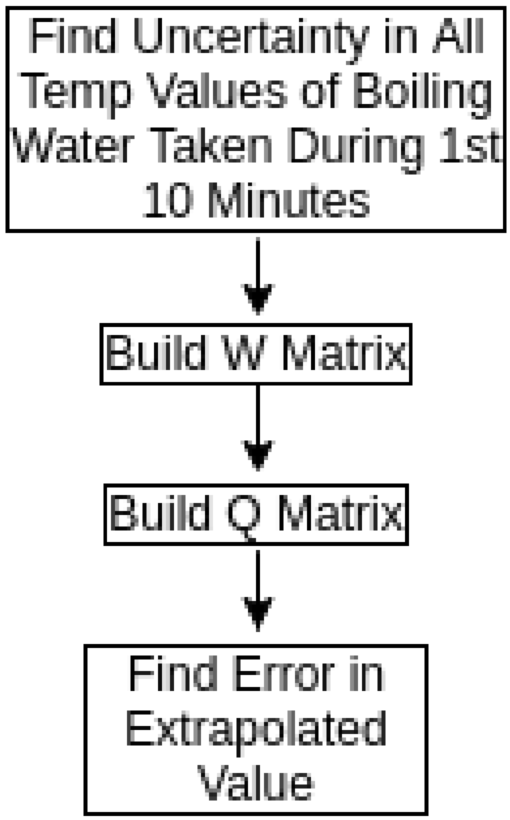

Fig. 10 Subroutine 7: findsigT2 Algorithm Flow Chart

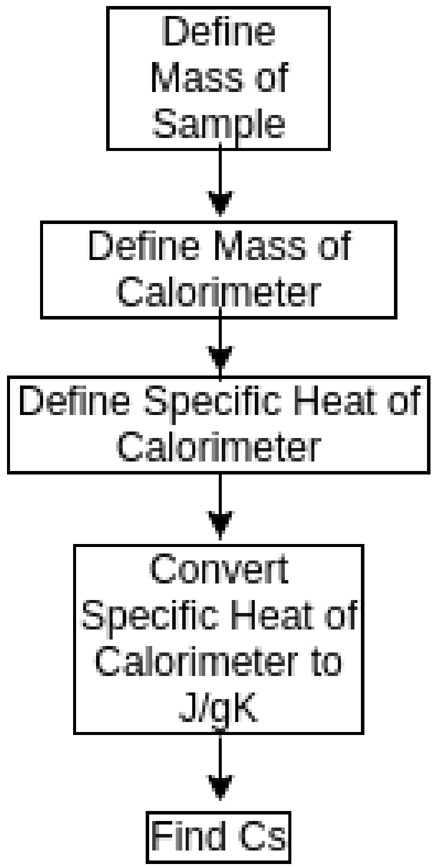

Fig. 11 Subroutine 8: findcs Algorithm Flow Chart

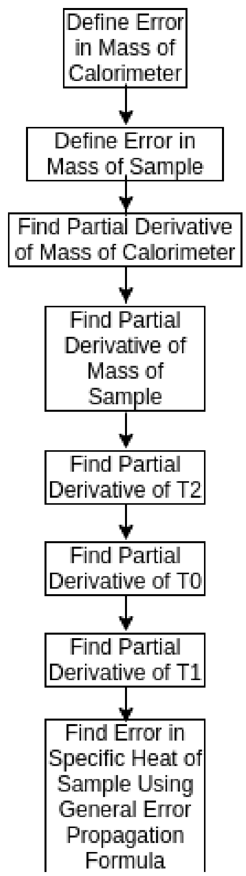

Fig. 12 Subroutine 9: findsigcs Algorithm Flow Chart

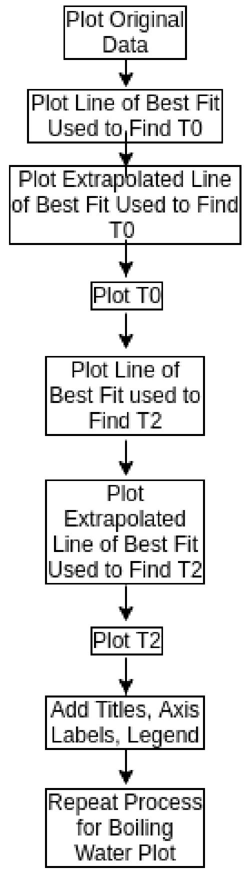

Fig. 13 Subroutine 10: createplots Algorithm Flow Chart

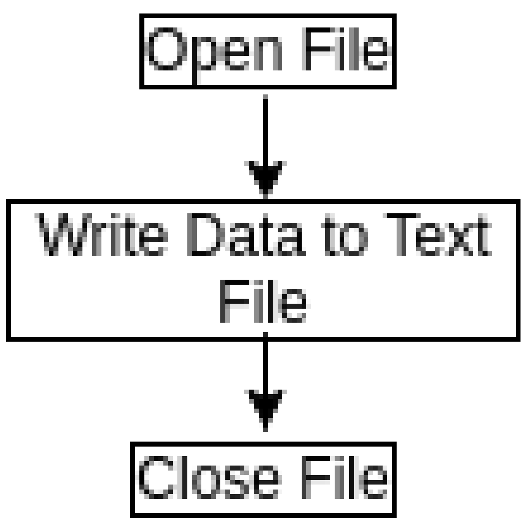

Fig. 14 Subroutine 11: writeoutput Algorithm Flow Chart