Momentum: Physics Education Journal
7 (1), 2023, 78-92
Available at: ejournal.unikama.ac.id/index.php/momentum
ISSN 2548-9127(print) | 2548-9135 (online)

Derivation of Newton's law of cooling and heating: Heating the water then cooling it down naturally to the room temperature

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Received: 1 September 2022; Revised: 9 December 2023; Accepted: 10 January 2023

Abstract: A simple experiment has been conducted to study Newton's law of cooling and heating by observing the nature of the increasing and decreasing water temperature by utilizing a data logger, a thermocouple, a pan, a hot plate, and water. The uncovered pan contained water which was subsequently heated on a hot plate. The water was heated at ambient temperature and normal atmospheric pressure to see that the temperature rose exponentially. Conversely, the temperature of hot water decreased exponentially when the heat source was switched off. The model for increasing and decreasing water temperature is following the Newton's law of cooling and heating. It was proven that the experimental data highly fit theoretical models. The temperature increment constant (k_a) and the temperature decrement constant (k_d) determined the rate of temperature changes. Low values of k_a and k_d led to the slow change in the temperature, either the increase or the decrease in the water temperature and vice versa. The $k_a > k_d$ was observed for all given conditions so that the increasing rate in the water temperature was faster than its decrease. The result of this study can be applied as an example of contextual learning of physics for university students

Keywords: experiment; water temperature; heating; Newton's law of cooling; physics learning

How to Cite: Wibowo, E., Ulya, N., Farizi, M. R., & Fitriyanti, N. (2023). Derivation of Newton's law of cooling and heating: Heating the water then cooling it down naturally to the room temperature. *Momentum: Physics Education Journal*, *7*(1), 78–92. https://doi.org/10.21067/mpej.v7i1.6889

Introduction

Many activities or occurrences around us can be used as learning tools in science education (Abdullah et al., 2014; Abdullah et al., 2020; Aleksandrov et al., 2013; Aslani & Moghiman, 2019; Fallahnezhad & Reza Nazif, 2019; Nelson et al., 2020; Wibowo et al., 2016; Will et al., 2017). Contextual approaches need to be involved instead of textual practices in conducting science learning to become more understandable and fun, especially in physics subject (Dale et al., 2019; Jelicic et al., 2022; Sokolowski, 2021). Through contextual approaches, the learning content that students are studying will look more accurate and easily imagined. The students faced difficulty in understanding learning content in a physics course, primarily because of the student’s inability to visualize the theory or concept being learned (Onder et al., 2018; Vilarta Rodriguez et al., 2020). Therefore, physics teachers who only convey learning content theoretically according to the textbook without showing the actual phenomenon need to change their teaching methods (Dunnett et al., 2019; May et al., 2022). The teacher needs to take a contextual approach (Meltzer, 2021; Wagoner et al., 2018), especially by utilizing students' daily experiences, so that what the teacher conveys becomes easily imagined and captured by the students (Christensen et al., 2022; Larsson & Airey, 2021; Pols et al., 2019; Pols et al., 2021).

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DOI: 10.21067/mpej.v7i1.6889

Boiling the water to make a cup of tea or coffee is an everyday activity in the morning. Many people already have experiences in boiling some water, or at least they have ever seen this activity. We have known that the water is gradually getting hot when it is heated. But, if we are asked, how does the pattern of the increment of water temperature when it is heated? Then, after the water is hot and we used to make a cup of coffee, we do not drink it but put it on the table, so over time, the coffee becomes cold. How does the decrement pattern of coffee temperature? Maybe we are not able to answer these questions even though it happens in our daily lives. Many activities that we do in our daily lives are related to the physics phenomenon (Silva et al., 2018; Vandervoort, 2020; Wang et al., 2022). However, we often did not realize it. Boiling the water to make a cup of coffee or tea is an activity that involves the physics phenomenon. Hence, we can make the activity of boiling water a tool to conduct contextual learning. Students have been taught the theories and concepts of temperature, heat, and heat transfer in the class. Also, they have studied that heat can flow from high-temperature substances to lower-temperature substances spontaneously; the reverse process cannot spontaneously occur. If the object is heated, the object's temperature will increase. Conversely, if the object is cooled its temperature will decrease. Heat can flow by conduction, convection, and radiation. This theoretical knowledge will be more deeply understood if the students are invited to do or directly witness the activity that involves the implementation of these theories (Bauer & Chan, 2019; Foote & Martino, 2018). In the boiling of water, a heat transfer process occurs and leads to an increase in water temperature. The heat is transferred from the heat source to water through the container by conduction. The propagation of heat follows it to all parts of the water by convection (Pacheco et al., 2022). Conversely, if the heat of hot water is released into the air, the water temperature cools down. We can observe all these theories and concepts in heating water when we make a cup of coffee or tea.

In addition to conducting contextual learning regarding heat and heat transfer, in this paper, we present the learning process on how to construct a model to describe physics phenomena through a simple experiment, i.e., heating of water. The physics phenomenon that would be modeled is the increase of the water temperature when heated and the decrease of hot water temperature due to heat transfer from the water to the air. We have known that the model for decreasing water temperature is following Newton's law of cooling. Studies related to Newton's law of cooling have been reported by several authors (Aghayari et al., 2020; Bastos et al., 2022; Brody & Brown, 2017; Chanthamanee et al., 2022). However, the derivation of Newton's Law formula was not deeply discussed. Even though it is interesting because will enrich students' understanding regarding Newton's Law. Therefore, in this work, we showed how Newton's law of cooling and heating is derived from the experiment. We have proved that the models are reasonably fit for the experimental data.

Method

This experiment was conducted to describe the model of the increment and the decrement of water temperature. We used water, a small pan, a hot plate, a thermocouple, and a data logger. We put water in the uncovered pan, and then it was heated using a hot plate. We carried out the heating process of water at room temperature and atmospheric pressure. A thermocouple and data logger were used to record the change in water temperature. We varied the volume of water and the heat source temperature. We used 500 ml, 1000 ml, and 1500 ml of water, while the temperature of the hot plate was set at 96 °C, 119 °C, 176 °C, and 273 °C.

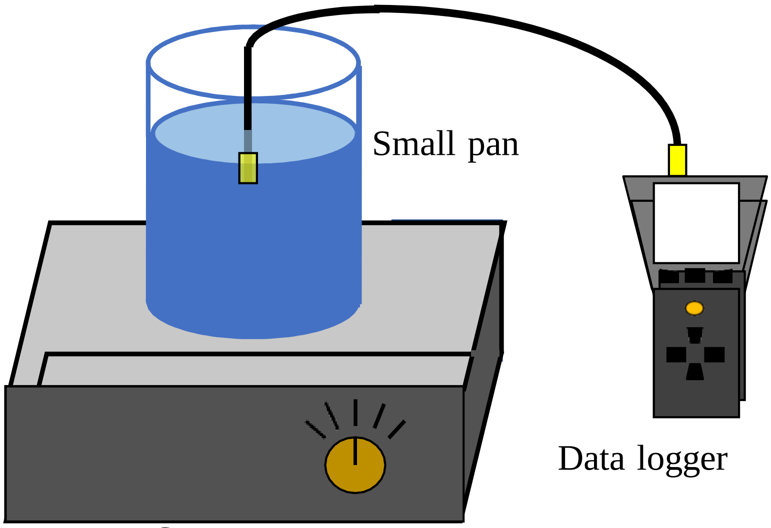


Figure 1. The Illustration of the Experimental Setup

We plot the obtained data to the graph of temperature as a function of time. We received two types of charts, the increase in water temperature and the decrease in water temperature. We constructed two models to describe the rise in water temperature and the reduction of hot water temperature to room temperature. We plot the models and then compare them to the obtained data to verify the model's validity. The illustration of the experimental setup is shown in Figure 1 and the obtained data are presented in Table 1.

Table 1. The experimental of heating water

Time (s)	Water temperature (°C)		
	500 ml	1000 ml	1500 ml
0	24.3	25.4	25.0
30	24.3	25.6	26.9
60	24.3	25.6	28.5
90	24.6	27.4	30.1
120	24.5	29.7	31.8
150	24.5	32.1	33.1
180	24.5	34.3	34.9
210	24.3	36.0	36.5
240	29.0	38.0	37.9
270	33.3	40.1	39.5
.	.	.	.
.	.	.	.
.	.	.	.
7800	25.2	21.9	28.9

Results and Discussion

Model for the Increment and Decrement of Water Temperature

This work aims to demonstrate and give insight into conducting contextual learning through a simple daily activity. Boiling the water to make a cup of coffee or tea is a typical daily activity. It is straightforward; everyone can do it. Due to it having been becoming a routine, this activity becomes usual, and does not look attractive. We all know that the water temperature will increase when it is heated, and then it will return to room temperature when we let it naturally cool down. However, most of us cannot explain how the form of the increment of water temperature when it is heated. Some of us do not notice whether it is increased linearly, exponentially, or quadratically. Likewise, when the hot water is allowed to cool down to room temperature naturally, how does its temperature decrement? It's not easy to answer even for physics students who often observe or usually do it. Many physics concepts are involved in heating water, such as heat, heat transfer, thermal adsorption, thermal desorption, conduction, convection, and evaporation (Johal, 2023; Kaufman & Leff, 2022; Roll, 2020; Suryadi et al., 2020). Therefore, many scientific phenomena can be learned from this activity.

In this paper, we report the results of our observation and investigation of heating water activity. The experiment was started by heating 1000 ml of water on the uncovered pan using an electric stove as a heat source. The temperature of the hot plate was set at 176 °C, and a data logger was used to record the temperature change of water during the experiment process. The heat transfer phenomenon, as well as the increment and decrement of water temperature, were observed. Based on this obtained data, we derivate the models to describe how the water temperature increases when it is heated and how the decrement of hot water temperature when we let it naturally cool down to room temperature. The plot of experimental data for heating water is presented in Figure 2.

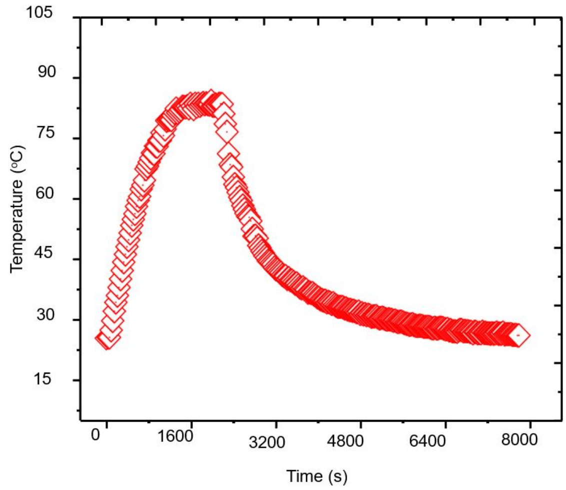


Figure 2. The change of water temperature in the uncovered container when it is heated.

The volume of water is 1000 ml, while the temperature of the heat source was set at 176 °C. In the beginning, when the source of heat is switched on, the temperature of the water is exponentially increased, and then it is exponentially decreased to room temperature when the source of heat is switched off.

Figure 2 shows the increment of water temperature when it is heated and decreases since the heat source is switched off. We can see that the temperature of water rapidly increases when it is heated. However, with the increase of time, water temperature increment is gaining slow and finally stops. No more water temperature increment event though the heating time is continued. When the heat source is switched off, the temperature of hot water rapidly decreases and then finally stops when it reaches room temperature. With the increase of time, the decrement of water temperature becomes slow and then vanishes as well. Based on this result, we know that either the increment or the decrement of water temperature has an exponential pattern. It exponentially increases when the water is heated and exponentially decreases when the hot water temperature is naturally cooling down to room temperature (Bastos et al., 2022; Vandervoort, 2020).

After we succeed in showing the pattern of increasing and decreasing water temperature - it has an exponential pattern. Then, we are going to express the form of the exponential function of these patterns. Firstly, we divided the graph in Figure 2 into two separated parts, the graph of temperature increases and the graph of temperature decrease, as shown in Figure 3. Based on Figure 3, the exponential pattern of the increment of water temperature (Figure 3.a) and the exponential pattern of the decrement of water temperature (Figure 3.b) were becoming more clearly observed. The next step was creating the exponential model of each condition, starting by the derivation model for the increment of water temperature and then followed by the model for decrement of water temperature. For the increment of water temperature model (Figure 3.a), it can be observed that the increase in water temperature is proportional to the increment of time. Consider the water temperature as a function of time is T_t, whereas the maximum water temperature at a given heat source is $T_{e,\ max}$. We see that if time increases for Δt, so the increment of water temperature is proportional to the interval time and the remaining ranges of water temperature could be increased. After reaching a certain temperature, the increase in water temperature will saturate. We expressed this remaining range to saturate as $T_{e,max}$ - T_t. Thus, the additional temperature of the water when it is heated meets

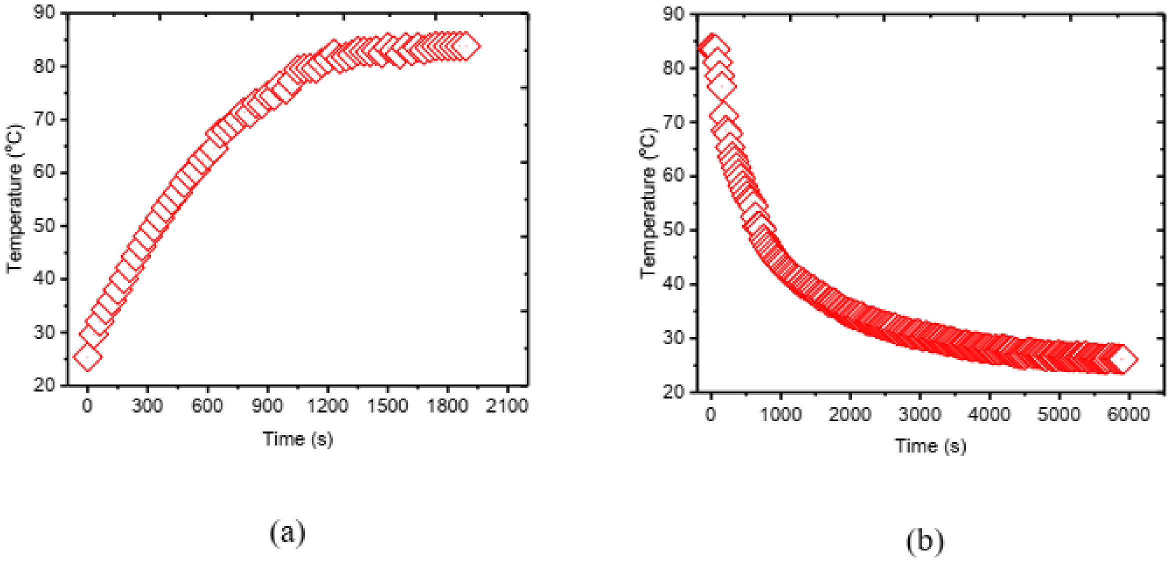


Figure 3. The change of water's temperature as a function of time. (a) The increase in water temperature, (b) The decrease of water temperature. The volume of water was 1000 ml while the heat source temperature was set at 176 °C.

$$\Delta T_t \infty (T_{e,max} - T_t)\Delta t \quad (1)$$

By taking *dt* → 0, the expression (1) turns into the following differential form:

$$dT_t \infty (T_{e,max} - T_t)dt \quad (2)$$

This mathematical expression can be rearranged into an equation by introducing a constant, *ka*. Then expression (2) becomes

$$dT_t = k_a(T_{e,max} - T_t)dt \quad (3)$$

$$\frac{dT_t}{(T_{e,max} - T_t)} = k_a dt \quad (4)$$

By integrating both of side Eq. (4) with the boundaries condition from *t* = 0 to *t* = *t* and *Tt* = 0 to *Tt* = *Te, max*, we obtain the model of the increase of water temperature as follows

$$\int_{T_0}^{T_t} \frac{dT_t}{(T_{e,max} - T_t)} = \int_0^t k_a\, dt \quad (5)$$

$$ln(T_{e,max} - T_t)\Big|_{T_0}^{T_t} = -k_a t\Big|_0^t \quad (6)$$

$$\ln(T_{e,max} - T_t) - \ln(T_{e,max} - T_0) = -k_a t \quad (7)$$

$$\ln\left(\frac{T_{e,max} - T_t}{T_{e,max} - T_0}\right) = -k_a t \quad (8)$$

$$\frac{T_{e,max}-T_t}{T_{e,max}-T_0} = e^{-k_a t} \tag{9}$$

$$T_{e,max} - T_t = (T_{e,max} - T_0)e^{-k_a t} \tag{10}$$

$$T_t = T_{e,max} - (T_{e,max} - T_0)e^{-k_a t} \tag{11}$$

Now, we obtained Eq. 11 as an expression of the theoretical model for the increment of water temperature with T_0, T_t, $T_{e,max}$, t, and k_a are the initial of water temperature, the water temperature at a certain time, the saturate water temperature, time, and the temperature increment-constant, respectively. The initial temperature (room temperature) always lower than the saturate temperature (T_0 < $T_{e,max}$). The value of k_a can be obtained by plotting the experimental data by using Eq. 7. Then, for the model of decreasing the water temperature, we have used a similar analogy with the previous assumption. Consider the water temperature as a function of time is T_t, and the equilibrium temperature after cooling down to the room temperature is $T_{e,min}$, so we can express the decreasing of hot water temperature as

$$\Delta T_t \infty (T_{e,min} - T_t)\Delta t \tag{12}$$

By using similar steps with the previous derivation, we obtain

$$dT_t = k_d(T_{e,min} - T_t)dt \tag{13}$$

$$dT_t = -k_d(T_t - T_{e,min})dt \tag{14}$$

$$\frac{dT_t}{(T_t - T_{e,min})} = -k_d dt \tag{15}$$

$$\int_{T_0}^{T_t} \frac{dT_t}{(T_t - T_{e,min})} = \int_0^t -k_d\, dt \tag{16}$$

$$ln(T_t - T_{e,min}) \Big|_{T_0}^{T_t} = -k_d t\Big|_0^t \tag{17}$$

$$\ln(T_t - T_{e,min}) - \ln(T_0 - T_{e,min}) = -k_d t \tag{18}$$

$$ln\left(\frac{T_t - T_{e,min}}{T_0 - T_{e,min}}\right) = -k_d t \tag{19}$$

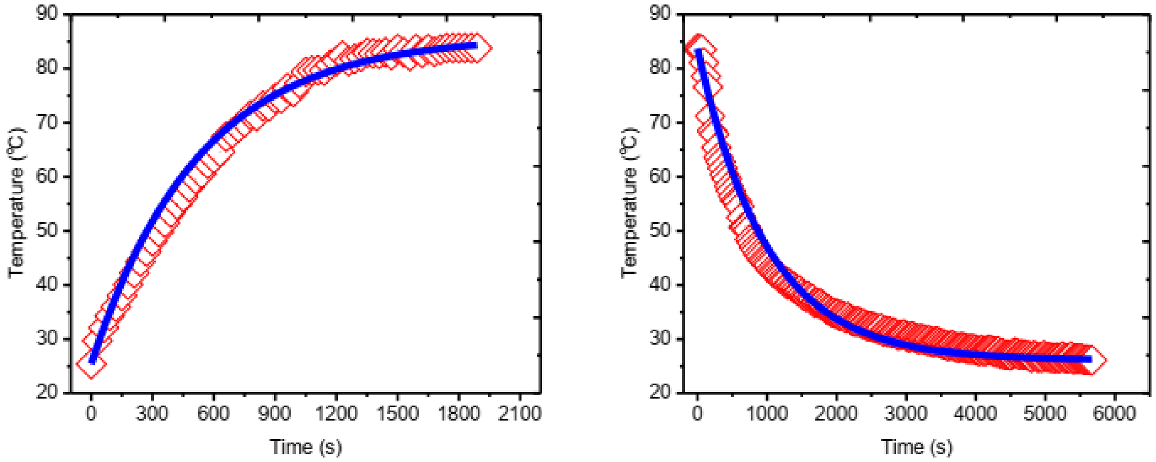
$$\frac{T_t - T_{e,min}}{T_0 - T_{e,min}} = e^{-k_d t} \tag{20}$$

$$T_t - T_{e,min} = (T_0 - T_{e,min})e^{-k_d t} \tag{21}$$

$$T_t = T_{e,min} + (T_0 - T_{e,min})e^{-k_d t} \tag{22}$$

Eq. 22 is a theoretical model for the decrement of hot water temperature when naturally cool down to the room temperature with T_0, T_t, $T_{e,min}$, t, and k_d are the initial of hot water temperature, the water temperature at a certain time, saturate water temperature (room temperature), time, and the temperature decrement-constant, respectively. In this condition, the initial temperature (hot water temperature) is always higher than the saturated temperature, T0 >$T_{e,min}$. The increased temperature constant, kd can be obtained by linearly plotting the experimental data by using Eq. 18. Eq. 11 is an expression of Newton's law of heating, while Eq. 22 implies Newton's law of cooling (Bastos et al., 2022; Chanthamanee et al., 2022; Galeriu, 2018).

Figure 4 shows the fitting of the theoretical model (Eq. 11 and Eq. 22) to the experimental data. Figure 4a shows the increase in water temperature that was fitted to the theoretical model (Eq. 11), while Figure 4b shows the decrease in water temperature that was fitted to the Eq. 22. The symbols are the experiment data while the curve is the plot of the theoretical model which is highly fit the experimental data. The increase of the water temperature well described by Eq. 11, whereas the decrease of hot water temperature well described by Eq. 22. It means the theoretical models can be correctly used to describe the experimental data.



(a) (b)

Figure 4. Fitting of the theoretical model with the experiment data of the change of water temperature. (a) The increment of water temperature, (b) The decrement of water temperature. Symbols are the experiment data while the curve is the plot of the theoretical model.

Temperature Increment-Constant (k_a) and Temperature Decrement-Constant (k_d)

Based on Eq. 11 and Eq. 22, we can see that the rate of the increase and the decrease in water temperature depending on the value of k_a and k_d, respectively. The small value of k_a and k_d indicate the slow process, whereas the higher value of k_a, and k_d show the faster process either in the rising of water temperature or in the decreasing of water temperature. Therefore, the parameters that determine the value of k_a and k_d will be discussed. When the water in the container is heated, the heat is conductively transmitted from the stove to the water container (small pan). Then, when the heat reaches the water, it is convectively transferred to the whole part of the water inside the container so that the water temperature gradually increases. In this condition, the heat convection is governed by Newton's Law (Will et al., 2017) as follows:

$$P = \frac{dQ}{dt} = hA\Delta T \quad (23)$$

with $P = dQ/dt$ is convective heat transfer or heat transfer rate (W), h is a convective heat transfer coefficient of water (W/m^2. ℃), A is the surface area where the heat transfer takes place (m2), and ΔT is a temperature difference between the container and the water inside the container (℃). By considering $dQ = mcdT_t$ with m is the mass of water, and c is the specific heat of water (Pacheco et al., 2022). so that we obtained:

$$mc\frac{dT_t}{dt} = hA\Delta T \quad (24)$$

$$dT_t = \frac{hA}{mc}\Delta T dt \quad (25)$$

$$dT_t = \frac{hA}{mc}(T_{e,max} - T_t)dt \quad (26)$$

By defining, $k_a = \frac{hA}{mc} = \frac{hA}{\rho V c}$, with ρ is the water density and V is the volume of water, then Eq. 26 can be written into Eq. 27. Now, we can see that Eq. 27 is the same form as the Eq. 3, therefore, we obtain the final expression of Eq. 27 as follow:

$$dT_t = k_a(T_{e,max} - T_t)dt \quad (27)$$

$$\frac{dT_t}{(T_{e,max} - T_t)} = k_a dt \quad (28)$$

$$\int_{T_o}^{T_t} \frac{dT_t}{(T_{e,max} - T_t)} = \int_0^t k_a\, dt \quad (29)$$

$$T_t = T_{e,max} - (T_{e,max} - T_0)e^{-k_a t} \quad (30)$$

Meanwhile, for decreasing hot water temperature, heat is naturally released from the water to the air convectively. Hence, this process was also governed by Newtons' law as expressed in Eq. (23) but with different values of *h*. In this case, *h* is a convective heat transfer coefficient of air, where *h* of air (6 - 30 W/m2. ℃) is smaller than *h* of water (20-100 W/m^2. ℃) (Elmardi, 2017). Therefore, the value of k_a is always higher than k_d. By recalling Eq. (26) then conduct mathematic manipulation, we obtain:

$$dT_t = -\frac{hA}{mc}(T_t - T_{e,min})dt \quad (31)$$

$$dT_t = -k_d(T_t - T_{e,min})dt \quad (32)$$

$$\frac{dT_t}{(T_t - T_{e,min})} = -k_d dt \quad (33)$$

$$\int_{T_o}^{T_t} \frac{dT_t}{(T_t - T_{e,min})} = -\int_0^t k_d\, dt \quad (34)$$

$$T_t = T_{e,min} + (T_0 - T_{e,min})e^{-k_d t} \quad (35)$$

We obtained the same expression of the model for the increase of the water temperature (Eq. 30 and Eq. 11), and the model for the decrease of the water temperature (Eq. 35 and Eq. 22) even though they were derived from a different approach. Eq. 11 and Eq. 22 were obtained based on an interpretation of the experimental data, while Eq. 30 and Eq 35 were derived from Newton's Law for convective heat transfer. We can see that k_a and k_d are linearly proportional to the convective heat transfer coefficient, and the surface area where the heat transfer takes place, as well as inversely proportional to the water density, the volume of water, and the heat specific of water.

Variation in the Water Temperature

To further verify the validity of the theoretical models, we conducted a set of experiments using the same volume of water with the previous experiment (1000 ml) but using different heat source temperatures i.e., 96 °C, 119 °C, and 273 °C. We used experimental data that was conducted at a temperature of 176 °C as a reference. If the theoretical models are correct, it can be used to describe the experimental data correctly even though the water was heated by different heat source temperatures. The obtained data are shown in Figure 5, while the comparison of the theoretical model to the experimental data is shown in Figure 6.

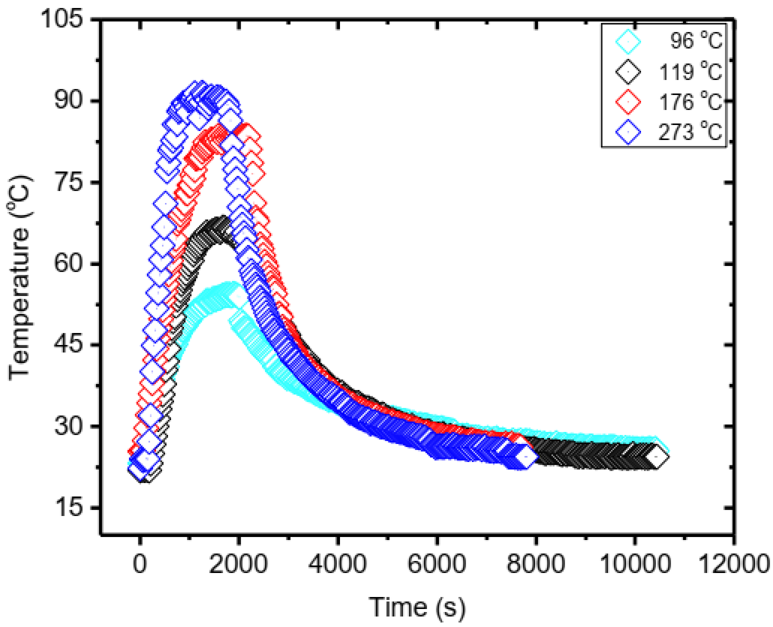


Figure 5. Comparison of the pattern of water temperature-change with different temperatures of the heat source

Based on Figure 5, we can see all the experimental data have a similar trend, for example, an exponential form. Besides, we see that the water that was heated by a higher heat source temperature will heat-up faster and reach a higher maximum saturate temperature compared to the water that was heated by a lower heat source temperature. The maximum saturate temperature ($T_{e,max}$), as well as the increase and the decrease temperature constants (k_a and k_d) are presented in Table 2. From Figure 6, we can see that the plot of experimental data highly fits the theoretical model. These results confirmed the validity of the models. It means the pattern of the increase and the decrease in water temperature have been successfully described by the models.

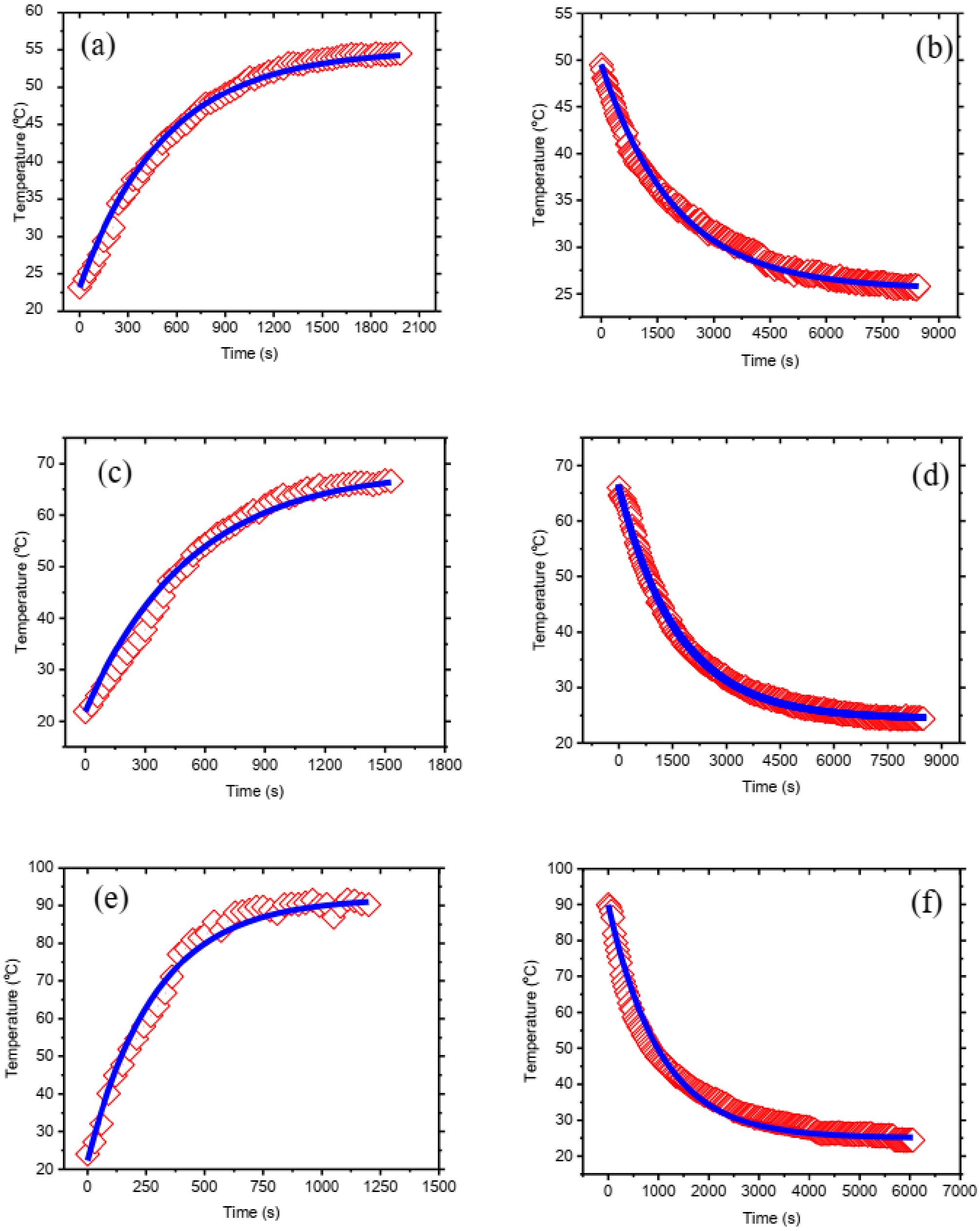


Figure 6. The comparison of the theoretical model to the experimental data with the variation of heat source temperature. Symbols are experimental data while the curve is the theoretical model. (a, b) when the water is heated at the temperature of 96 °C, (c, d) when the water is heated at the temperature of 119 °C, and (e, f) when the water is heated at the temperature of 273 °C

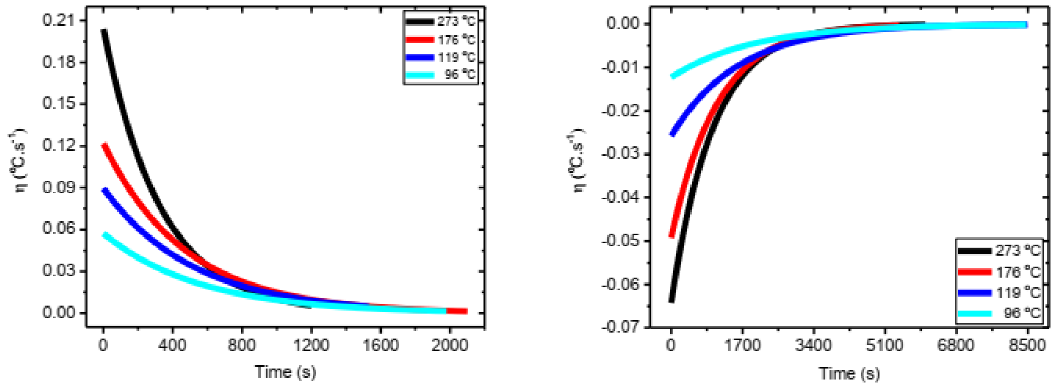
From Table 2 we obtained the following information. First, the maximum saturate temperature ($T_{e,max}$), the saturate time ($t_{e,max}$), the increasing temperature constant (k_a), and the decreasing temperature constant (k_d) rise by the increase of the heat source temperature. All these parameters highly depend on the heat source temperatures. The low temperature of heat source produces a low value of $T_{e,max}$, k_a, and k_d but a high value of $t_{e,max}$. In contrast, the high temperature of heat source produces a high value of $T_{e,max}$, k_a, and k_d, but a low value of $t_{e,max}$. At a low temperature of heat source, the change of water temperature goes slowly, while at a higher temperature of heat source, the change of water temperature goes faster. Second, we show that the value of k_a is always higher than k_d, it indicates that the raising of water temperature is always faster than the decreasing of water temperature for given conditions. The slow process, either in the raising or in the decreasing of water temperature were identified by the small value of k_a, and k_d. In contrast, the fa ster process was characterized by the higher value of k_a, and k_d. These results are in line with the theoretical prediction that was discussed previously.

Table 2. The Value of *Te, max, te, max, ka*, and *kd* for Different Heat Source-Temperature, *T*

No	Heat source-temperature, *T* (°C)	*Te, max* (°C)	*te, max* (minutes)	*ka* (s^{-1})	*kd* (s^{-1})
1	96	54.4	33	18×10^{-4}	51×10^{-5}
2	119	66.7	26	19×10^{-4}	62×10^{-5}
3	176	83.8	21	21×10^{-4}	90×10^{-5}
4	273	91.4	19	30×10^{-4}	99×10^{-5}

Based on Figure 7, we can see that by the increase of time, the rate of the increase and the decrease of the water temperature was decreased, and finally stop when the saturated temperature was achieved. It can be seen, the water that was heated by the high temperature has a high-rate value. By decreasing the heat source temperature, the rate of the temperature changes also decreased. Besides, we can see that the rate of the increase of the water temperature is higher than the rate of the decrease of water temperature for all given conditions. The maximum rate of temperature change of the water that was heated at a temperature of 273 °C is 0.20 °C/s for η_a, and 0.06 °C/s for η_d. For the water that was heated at a temperature of 176 °C, the maximum value of η_a, and η_d is 0.12 °C/s, and 0.05 °C/s, respectively. For the water that was heated at a temperature of 96 °C has a lower value, η_a = 0.06 °C/s, and η_d = 0.01 °C/s.

The increase in the temperature of the water in the container when it is heated occurs due to the heat transfer from the heat source to the water through the container. Because the heating process occurs in an open space, the heat from the heat source (Q_s) is not entirely used to heat the water, but some of them are dissipated into the environment (Q_1). Therefore, the heat that is transferred to the container is $Q_c = Q_s - Q_1$. Likewise, the heat of the container is also not entirely used to heat the water, some of them are transferred to the environment (Q_2). Therefore, the heat that is transferred to the water is $Q_c' = Q_c - Q_2$. Consequently, the highest temperature that can be reached by the water is very dependent on the temperature of the container and its lower dan heat source temperature. If the maximum temperature of the container wall due to Q_c' is $T_{e,max}$, then the highest temperature that can be reached by the water in the container is also $T_{e,max}$. The heat from the container will be convectively transmitted to all parts of the water until the temperature of the water becomes the same as the temperature of the container wall. In the beginning, the temperature difference between the container wall and the water is of the maximum value. As a result, heat from the container will speedily flow into the water. By the increase of time, the temperature of the water increases so that the heat difference will decrease. This condition causes the rate of heat flow to decrease. When the temperature of the water is the same as the temperature of the container wall, there is no more heat flowing from the wall to the water so that the rise in water temperature will stop (Chanthamanee et al., 2022; Will et al., 2017). There is no longer an increase in water temperature. It means the saturation condition has been achieved. That is why the rise in water temperature has an exponential pattern. It occurs rapidly in the beginning, then slows down with the increase of time and finally stops when the equilibrium condition is achieved. The temperature of the container wall can be raised or lowered by adjusting the temperature of the heat source. If the heating temperature is raised, the temperature of the container wall will also increase so that the saturate temperature that can be reached by the water will also increase. In contrast, if the temperature of the container wall is lowered but it's still above the room temperature, the saturated temperature will also drop. Hence, when the water is heated at low temperatures it has a low saturate temperature. On the other hand, if the water is heated at higher temperatures, the water will be able to reach a higher saturate temperature (Johal, 2023; Vandervoort, 2020).



(a) (b)

Figure 7. The rate of the increase and the decrease in water temperature. The experiment was conducted with the variation of heat source temperature i.e., 96 °C, 119 °C, 176 °C, and 273 °C. (a) the rate of the increment of water temperature, (b) the rate of the increment of water temperature.

Shortly after the heat source has been turned off, the water in the container has a much higher temperature (T_o) compared to the temperature of the surrounding air ($T_{e,min}$). As a result, heat flow occurs from water into the air. This is the opposite of the water heating process. In the beginning, the release of heat occurs quickly because the temperature difference between water and air is very high. As the process of releasing heat into the air, the water temperature becomes cooler. As a result, the temperature difference between water and air is getting smaller, so the rate of the release of heat to the air also slows down and then stops when the water temperature is equal to the temperature of the air. If this situation is reached, there will be no decrease in water temperature. This condition is called the low saturation state. Because it has this behavior, the decrease in water temperature has an exponential pattern. Similar results were also reported by some author (Bastos et al., 2022; Elmardi, 2017; Galeriu, 2018). The process of reducing the temperature slows down with the increase of time and then stops when it reaches air temperature. The value of the air convection coefficient is smaller than the value of the water convection coefficient. As a result, the process of releasing heat from water to air takes place more slowly than the process of heat flow from the walls of the container to the water. This causes the value of k_d to be smaller than the value of k_a as shown in Table 2. Physically it can be interpreted that the process of heating water will take place faster than the process of cooling water. Figure 7 shows a comparison of the rate of increase and decrease in water temperature. The rate of increase in water temperature is faster than the rate of temperature decrease.

From Figure 7 and Table 2, the water that is heated at a lower temperature is slower to reach the saturation temperature compared to the water that is heated at a higher temperature. When the water is heated with a heating temperature of 96 °C, the highest temperature that can be reached by the water is 54.4 °C within 33 minutes. Then, when the heating temperature is raised to 119 °C, the saturate temperature increases to 66.7 °C within 25 minutes. Furthermore, when the heating temperature is raised to 176 °C, the saturate temperature increases again to 83.8 °C in a shortened time i.e., 21 minutes. Finally, when the heating temperature is raised to 273 °C, the water temperature rises to 91.4 ° C within 19 minutes. The shorter the increment time is due to the process occurring at a higher speed. Conversely, the longer the increment time arises because the process has a lower speed.

At high heating temperatures, water has a higher temperature increment-rate than the water that is heated at lower temperatures. This is because the rate of heat transfer is proportional to the temperature gradient between the container wall and the initial temperature of the water (Brody & Brown, 2017; Galeriu, 2018). as expressed in Eq. 23. The greater the temperature difference, the higher the heat transfer rate. As a result, the rate of the increase in water temperature also becomes higher.

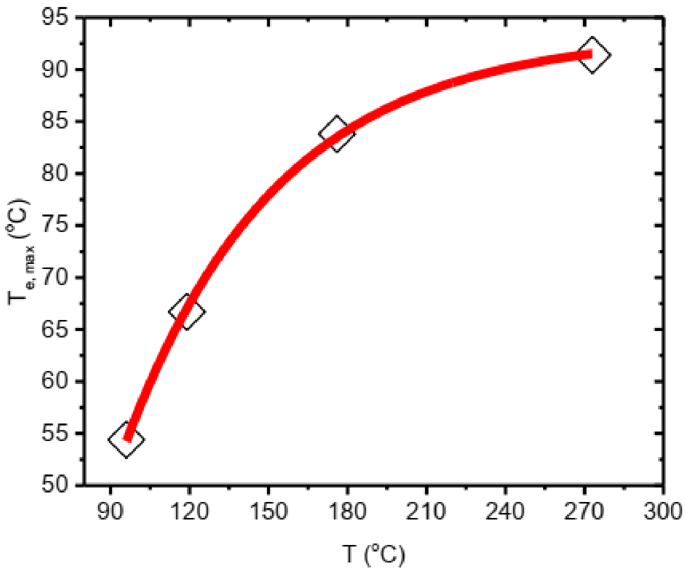


Figure 8. The relationship between the maximum saturate temperature ($T_{e,max}$) and the temperature of the heat source, *T*.

If we plot $T_{e,max}$ v.s. T in Table 2, we will obtain the graph as shown in Figure 8. The maximum saturate temperature that can be reached by water also increases exponentially with the increase in temperature of heat sources. This exponential pattern occurs due to there is a boundary (a limitation) of the liquid form of the water before changes to the gas. When approaching this boundary (transition zone), the heat that is received by the water is no longer used to raise the temperature but is used to change its form to the gas (Halliday et al., 2010). Therefore, the increment of water temperature has not further occurred. The water exists in a liquid form at a temperature of 0 °C - 100 °C (1 atm). It will in the ice form (solid) at below 0°C, and in a gas form at above 100 °C. The water will boil at a temperature of 100 °C. So that if the water is heated to this temperature, it changes from the liquid to the gas. In the previous discussion, the temperature of the container becomes a limitation of the maximum water temperature that can be achieved. The water temperature cannot exceed the temperature of the container. As a result, the increase in water temperature is also in exponential form. It is fast in the beginning and then gets slower and slower when the water temperature approaches the temperature of the container. For a capacitor, the capacitance of the capacitor itself becomes a limitation. After being fully charged, the capacitor is no longer able to store the electrical charge. The charging rate of the capacitor is slowing down during the charging process. Therefore, the exponential pattern of the charging process occurred. The charging and the discharging process of a capacitor are a well-known phenomenon in physics (Halliday et al., 2010) that are governed by the exponential patterns. In addition to the capacitor, the exponential patterns have also been observed in another phenomenon such as the adsorption process of ions (Wibowo et al., 2017).

Conclusion

We have carried out an experiment to investigate Newton's law of cooling and heating by examining the characteristics of the rising and falling water temperature. We have demonstrated how Newton's law of cooling and heating is followed by the model for rising and falling water temperatures. We established that theoretical models and experimental results closely matched. Here, the rate of temperature changes is controlled by the temperature increment constant (k_a) and the temperature decrement constant (k_d). Low ka and k_d values cause sluggish temperature changes, including both an increase and a fall in the water's temperature. For all the scenarios, we saw that $k_a > k_d$, meaning that the rate of increase in water temperature was greater than the rate of decline. From this simple experiment, which is usually carried out in daily life, we found many interesting phenomena. This activity and a similar one will encourage and challenge the students to strenghten their critical thinking. Proposing a model based on experimental data is a challenge for students. Maybe, it becomes a new experience for students who have only been taught textually. Through this contextual learning, the students are given the opportunity to become more involved in the learning process. They are allowed to observe and discover the beauty of science by themselves. This work can be used as an example of how contextual learning does was carried out through a scientific investigation.

Acknowledgment

We would like to thank the support of the Material Research Laboratory, Engineering Physics at Telkom University. All procedures conducted in this work followed the ethical standards of publication. Informed consent was obtained from all individual participants included in this work. The authors declare that they have no conflicts of interest.

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