



## DESIGNING CALORIMETER MADE FROM VARIOUS WASTES

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### ABSTRACT

A research has been conducted which aims to design a waste-based calorimeter as an alternative to measuring heat for chemistry practicum in schools. Research products developed through the steps of design-based research comprising the steps of analysis, design, and development. The resulting product is a waste-based calorimeter equipped with an automatic stirrer. The container to store the reagent solution on the calorimeter is made of Styrofoam, paper, plastic, melamine, PVC and bamboo. Optimization tool was conducted to determine the heat capacity of the calorimeter and the enthalpy of neutralization. The highest accuracy calorimeter value between 78-97%. Bamboo calorimeter has the highest accuracy value (97%). Styrofoam calorimeter has the lowest accuracy values (78%). Based on the results of the validation and feasibility test it can be concluded that the product is declared valid and feasible.

**Keywords:** *waste-based calorimeter, calorimeter heat capacity, enthalpy change of neutralization*

### INTRODUCTION

Chemistry is one branch of science that is very closely related to life so it needs to be learned by students. The concepts in chemistry are very broad, from simple concepts to very complex and abstract concepts [1]. The concept of chemistry is also obtained from experimental activities whose development is obtained through research activities. Therefore, practicum or experimental activities are needed in studying chemistry [2]. Practical activities make it easier for students to understand the concepts being learned [3]. Through practicum, students make direct observations of chemical phenomena [4].

One of the concepts of chemistry that needs to be studied accompanied by practicum

is thermochemistry. The concept of thermochemistry is a concept learned in Class XI in high school. Based on the national curriculum, the basic competencies of thermochemistry include aspects of knowledge that is understanding of various types of reaction enthalpy, Hess's law and the concept of bond energy [5]. The skill aspect developed is the determination of the change in reaction enthalpy by applying Hess's Law based on the enthalpy of formation or bond energy. Determination of the reaction enthalpy based on the results of heat measurement using calorimetry [6].

Generally, the determination of the heat of reaction in the school laboratory using a simple colorimetric insulator is made of

container. The working principle of a calorimeter is to measure changes in reaction temperature and heat capacity at constant pressure. Data obtained from measurements are used to determine the heat of the reaction by applying the Black Principle, [7].

Simple calorimeters available in school laboratories made of aluminum wrapped in plastic and equipped with a manual stirring rod with a ring-shaped end. Based on preliminary experiments conducted by researchers, it was found that there were problems with accuracy in determining the calorimeter heat capacity. The value of the calorimeter heat capacity produced is always negative. This shows that the calorimeter releases heat. Theoretically, the calorimeter should absorb heat and the value of the resulting heat capacity is positive [8],[9]. Allegedly, this is due to the stirring rotation manually is not constant. In addition, the hand directly touches the ring-shaped stirrer resulting in heat transfer.

Several studies have used a calorimeter made of styrofoam [7], [10], [11], paper [12], and plastics [13]. These studies use automatic magnetic stirrers which produce high measurement accuracy. At school, the use of magnetic stirrers is an obstacle. Not all school laboratories have a magnetic stirrer. The price of magnetic stirrer is quite expensive and can only be used in places that have electricity sources. Thus, the use of magnetic stirrers is less economical and practical. However, replacing the insulator material on the calorimeter using Styrofoam, paper, and plastic can be followed. These materials are easily obtained in everyday life

and often become waste that pollutes the environment.

Based on this, the researcher considers it important to innovate a simple calorimeter used in school laboratories. The calorimeter isolator material is replaced with a variety of used materials available in the environment (other than those previously studied) and is equipped with self-made automatic stirrers. The innovation is expected to be developed in schools by teachers and students, thus providing an alternative tool or medium to carry out lab work more interesting and fun [14], [15].

## METHODS

The research product was developed using design-based research (DBR) [16]. This method consists of five stages, namely analysis, design, development, implementation, and evaluation. However, in this study only three steps were carried out, namely the analysis, design and development stages. [17].

The analysis phase is a theoretical and empirical study to get the results of the needs analysis. At the design stage, product design, tool and material determination and product packaging. At the development stage carried out: product optimization in the laboratory, validation and feasibility test. The product validation test was conducted by three chemists, while the eligibility test was conducted by 12 prospective teacher students. Data collected from the results of the validation test products were processed and analyzed by comparing the value of  $r$  count with critical  $r$  value set that is equal to 0.3 [18]. The feasibility value ( $r$  count) is determined using equation (1).

$$r = \frac{x}{N \cdot n} \quad (1)$$

The feasibility test data were analyzed by changing the frequency of answers from the questionnaire respondents into percentages. The questionnaire obtained from the respondent is given a score and then presented with equation (2):

$$\% = \frac{\sum n}{N} \times 100\% \quad (2)$$

Data obtained from the feasibility test are then interpreted using Table 1.

Table 1. Interpretation of Feasibility Percentage Value [19]

No.	Percentage (%)	Interpretation
1	90-100	very decent
2	80-89	worthy
3	70-79	pretty decent
4	60-69	not worth it
5	<60	not feasible

## RESULTS AND DISCUSSION

The prototype design of the Calorimeter was made to facilitate the process of making products that meet the validity and eligibility criteria. The design is outlined in the form of images that display concrete ideas that are attractive, efficient, and effective according to the usability criteria of the product [20], [21]. The intended product design includes: preparation of selection of insulator material for calorimeter containers, material for automatic stirrers and arrangement of product components. The insulating material for the reactant in the calorimeter must have a low thermal conductivity value.

Such materials cannot transfer heat from the system to the environment or vice versa [22]. Insulator material must be easily obtained in everyday life or utilize waste that can still be recycled. It is intended that products that are created are environmentally friendly and have low prices [23], [24].

Calorimeters from various simple materials are equipped with automatic stirrers which must have constant and uniform stirring specifications. For this reason, the mixer is connected to an electronic circuit that uses direct current (DC) electricity. The design of the automatic stirrer can be seen in Figure 1.

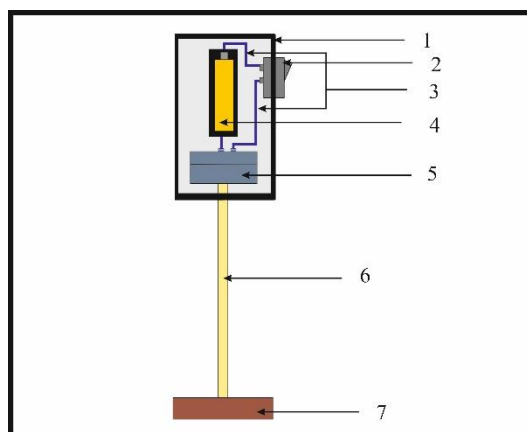


Figure 1. The desain of automatic stirrer

Caption:  
 1 = black box  
 2 = Switch  
 3 = Copper wire  
 4 = Battery  
 5 = Dynamo  
 6 = Stirring rod  
 7 = pinwheel of stirring

The desain of the calorimeter made from various wastes can be seen in Figure 2. Alternative materials used as reagent containers in calorimeters are Styrofoam, paper, plastic, melamine, PVC pipe (Polivynil Chloride), and bamboo. These materials are isolators that inhibit heat transfer from the system to the environment or vice versa [25].

The use of insulating material will produce a careful measurement of reaction heat. In this research we want to know which materials can more accurately produce heat measurements. Thus, the next step is to determine the thermal conductivity of each material.

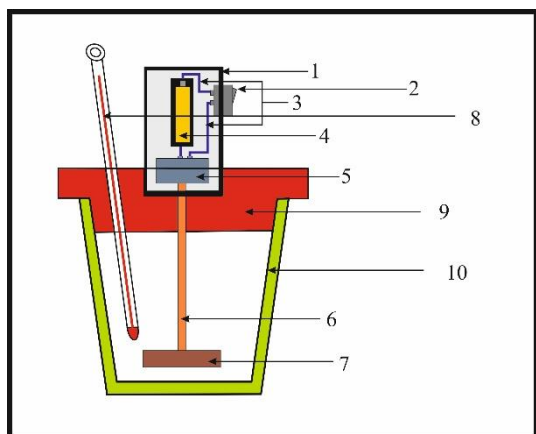


Figure 2. The design of calorimeter

- Caption:  
 1 = black box  
 2 = Switch  
 3 = Copper wire  
 4 = Thermometer  
 5 = Dynamo  
 6 = Cover  
 7 = Container  
 8 = Stirring rod  
 9 = pinwheel of stirring

The size of the container obtained varies according to the availability of material, because it comes from waste material that can still be used again. The calorimeter container size specifications can be seen in Table 2.

Table 2. The size of the calorimeter container from waste

Material	Diameter	Thickness	Height
Styrofoam	95 mm	2,8 mm	68 mm
Paper	77 mm	2,2 mm	80 mm
Plastic	80 mm	2 mm	70 mm
Melamin	70 mm	2,2 mm	75 mm
PVC	97 mm	3,2 mm	82 mm
Bamboo	69 mm	6 mm	9,8 mm

An automatic stirrer is composed of batteries, copper wire and dynamos. The circuit is placed on the black box which is connected with the stirring rod. Automatic stirrer can be seen in Figure 3.

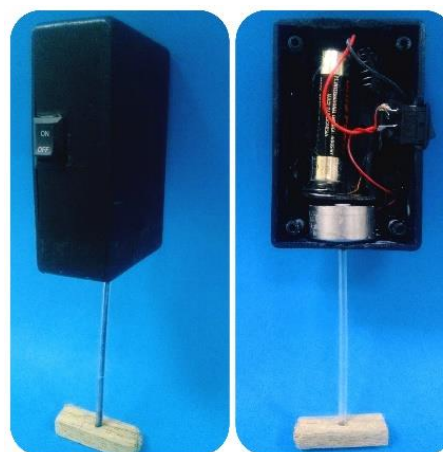


Figure 3. Automatic Stirrer

Stirrer rod material using waste plastic from the contents of the pen. Pinwheel of stirring using scrap wood. One of the calorimeter products made from bamboo can be seen in Figure 4.

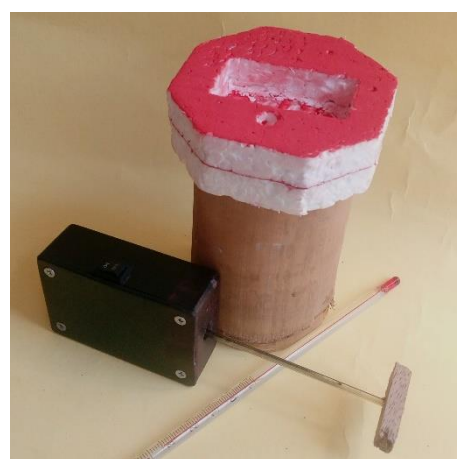


Figure 4. Calorimeter products made from bamboo

At the top of the container is closed with a styrofoam with a hole. The hole in the lid is used to place the automatic mixer and thermometer.

The next step is to determine the most optimal container material used for the measurement of heat. This is done by determining the heat capacity and enthalpy of the neutralization reaction. Determination of heat capacity of the calorimeter aims to determine the absorption of the calorimeter to heat. The calorimeter's heat capacity (Ccal) is the amount of heat absorbed to increase the temperature of the calorimeter by 1°C. [26].

Determination of heat capacity is done by mixing cold water and hot water. Initial and final temperatures are measured until a constant mixture temperature data is obtained. The data obtained is used to calculate the calorimeter heat capacity value. [27].

The procedure for determining the calorimeter's heat capacity is as follows: A total of 50 mL of cold water is put into the calorimeter and the calorimeter is closed. The automatic stirrer is turned on by pressing the switch. Water temperature is measured and recorded every minute up to five times the temperature reading. Then the automatic stirrer is turned off. As much as 50 mL of water (temperature  $\pm 50$  ° C) is put into a calorimeter that has been filled with cold water. The calorimeter is closed and the

automatic stirrer is turned on. The temperature of the mixed water is measured and recorded every one minute. Temperature measurements are carried out in order to obtain a constant temperature. In the experiment, the temperature of cold water and hot water were 28.5 °C and 54 °C respectively. The results of determining the calorimeter heat capacity can be seen in Table 3.

Based on Table 3, PVC pipe material has the largest Ccal value of 309,519 J / °C. Styrofoam has the lowest Ccal value of 81,881 J / °C. This Ccal value data is used to calculate the value of neutralization enthalpy change. Observation results when cold water is put into the calorimeter shows the calorimeter material does not absorb heat from cold water. This was proven by observations of temperature that did not change up to five times reading. Temperature changes occur after cold water is mixed with hot water. Recording temperature changes to a constant to ensure precise temperature change. The difference in temperature changes is used as data for calculating the heat capacity and heat of the reaction (change in reaction enthalpy) [28].

Table 3. The results of determining the calorimeter heat capacity

Material	Styrofoam	Paper	Plastic	Melamin	PVC pipe	Bamboo
Ccal (J/°C)	Experiment 1	66,500	114,950	209,000	292,600	292,600
	Experiment 2	89,571	114,950	209,000	248,188	343,357
	Experiment 3	89,571	143,000	209,000	248,188	292,600
	Average	81,881	124,300	209,000	262,992	309,519

Mixed water temperature data for each calorimeter from various simple materials is different. This shows that each calorimeter has a different heating capacity value,

because the thermal conductivity of each calorimeter container material is different. The order of thermal conductivity values starting from the smallest in a row is Styrofoam (0,08

W/mK), plastic (0,27 W/mK), PVC pipe (0,28 W/mK), melamine (0,40 W/mK), paper (3,45 W/mK), and bamboo (7,529 W/mK). [22], [29].

The Styrofoam calorimeter has the smallest Ccal value, while the PVC pipe calorimeter has the largest Ccal value. This shows that Styrofoam calorimeters have a better ability to withstand heat transfer from the system to the environment or vice versa [30]. Based on the value of thermal conductivity [22], the Ckal of a bamboo calorimeter should be greater the PVC pipe, because the thermal conductivity value is also greater. However, it is suspected that the size and thickness affect the Ccal value. PVC pipe calorimeters are relatively thinner than bamboo calorimeters [31].

Determination of the enthalpy change of neutralization is done with the following procedure: Prepare a solution of acid and alkaline solutions which have a number of moles and the same volume. The acid and base solutions used were 50 mL of 1 M HCl solution and 1 M NaOH solution, respectively. The temperature of 1 M HCl solution and 1 M NaOH solution were measured to determine the initial temperature. Then prepare the calorimeter that has been determined the value of the heat capacity. Then 50 mL of 1 M HCl is poured into the calorimeter. The calorimeter is closed and the stirrer is turned on. The temperature of the solution in the calorimeter is measured and recorded every minute for up to five times the temperature reading.

Table 4. The results of determining the change in neutralization enthalpy ( $\Delta H_n^\circ$ )

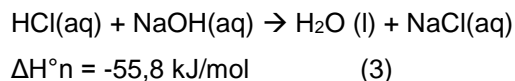
Calorimeter material	Styrofoam	Paper	Plastic	Melamin	PVC pipe	Bamboo	
$\Delta H_n^\circ$ (kJ/mol)	Experiment 1	-43,605	-45,834	-50,160	-52,584	-49,742	-52,584
	Experiment 2	-45,681	-47,966	-53,922	-49,298	-53,295	-56,848
	Experiment 3	-40,606	-50,490	-46,398	-53,295	-49,742	-53,295
	Average	-43,297	-48,096	-50,160	-51,726	-50,926	-54,242

After that the switch is pressed to turn off the stirrer. Then 50 mL of 1 M NaOH solution was poured into the calorimeter. The calorimeter is closed. The switch is pressed to turn on the stirrer. The temperature of the mix solution is measured and recorded every minute for up to five times the temperature reading. The temperature of the mixed solution in the calorimeter is observed and recorded every one minute. Temperature recording is carried out until a constant temperature is obtained. After that the switch is pressed to turn off the stirrer. The results of initial temperature measurement of HCl and NaOH

solutions are the same, which is 28.5 ° C. The results of determining the change in neutralization enthalpy ( $\Delta H_n^\circ$ ) can be seen in Table 4.

Based on Table 4, the greatest  $\Delta H_n^\circ$  value is found in the bamboo calorimeter which is -54,242 kJ / mol. While the smallest value of  $\Delta H_n^\circ$  is found on a Styrofoam calorimeter that is -43.297 kJ / mol. The result of  $\Delta H_n^\circ$  will be compared with the value of  $\Delta H_n^\circ$  theoretically so that the percentage of accuracy (% accuracy) of the calorimeter can be determined. The value of  $\Delta H_n^\circ$  is theoretically determined by changing the enthalpy of formation data for each ion involved in the

reaction [23]. The value of  $\Delta H_n^\circ$  reaction of HCl and NaOH can theoretically be seen in equation 3.



Percent accuracy of determining  $\Delta H_n^\circ$  by using calorimeters from various simple materials can be seen in Table 5.

Tabel 5. Optimization results in determining the value  $\Delta H_n^\circ$

No	Calorimeter Material	% accuracy
1.	Styrofoam	78
2.	Paper	86
3.	Plastic	90
4.	Melamin	93
5.	PVC pipe	91
6.	Bamboo	97

Based on Table 5, the biggest accuracy is in the bamboo calorimeter of 97%. While the smallest accuracy % is found on Styrofoam calorimeters by 78%. The  $\Delta H_n^\circ$  value measured using a bamboo calorimeter is closest to the theoretical  $\Delta H_n^\circ$  value.

The difference in the value of the change in neutralization enthalpy is due to the influence of the difference in the  $C_{cal}$  value on the calorimeter of various simple materials. Bamboo calorimeter produces the most optimal neutralization enthalpy change because it has a large  $C_{cal}$  value. Whereas the Styrofoam calorimeter produces the smallest neutralization enthalpy change in line with a small  $C_{cal}$  value. The heat absorbed by the Styrofoam calorimeter is small even though the temperature measurements in the neutralization reaction experience greater changes. The difference

in thickness of the material used also affects the data produced [22], [32].

Validation tests on the calorimeter from various waste materials were carried out by three validators. Validators are asked to test the product based on seven aspects, namely aspects of conformity with learning objectives, aspects of practicality, aspects of aesthetics and durability, aspects of equipment efficiency, safety aspects for students, environmental aspects, and aspects of clarity of instructions for use. During validation, the researcher shows and demonstrates the use of the product. The validator provides assessments and suggestions for improvement. The results of the assessment and suggestions for improvement are used to perfect the product, so it is ready for use for the next stage. The results of the validation test can be seen in Table 6.

Table 6. The results of validation test of product

No	Aspect	Result of validation
1	conformity with learning objectives	0,81
2	Practicality	0,83
3	Apearance and durability	0,75
4	Efficiency	0,81
5	Security	0,75
6	Environment	0,75
7	Clarity of use instructions	0,73
	Average	0,78

Based on Table 6, it can be seen that the highest value is found in the practical aspect with a calculated value of 0.83. While the lowest value is in the aspect of clarity of use instructions with a calculated value of 0.73. The average value of the count from all aspects is 0.78. From the results of validation on all aspects it can be concluded that calorimeters from various simple materials

are declared valid and ready to be tested. The input provided by the validator is the product is designed to have the same size and beautify the appearance of the product.

The feasibility test was carried out by conducting a limited test of 12 students who were divided into six groups. The student has attended and passed an energetics course. In this feasibility test, students assess calorimeter products from various simple materials with six aspects, namely aspects of practicality, aspects of aesthetics and durability, aspects of equipment efficiency, safety aspects for students, environmental aspects, and aspects of clarity of instructions for use. The results of the Feasibility Test can be seen in Table 7.

Table 7. The results of feasibility test of product

No	Aspect	feasibility results (%)	Interpretation
1	Practicality	97,22	Very feasible
2	Apearance and durability	87,50	feasible
3	Efficiency	97,22	Very feasible
4	Security	100	Very feasible
5	Environment	93,75	Very feasible
6	Clarity of use instructions	93,23	Very feasible
	Average	94,49	Very feasible

Based on Table 7, the overall rating is categorized as very feasible to use (average percentage of 94.49%). Based on that, calorimeters from various simple materials are ready to be used as learning media.

In the aspect of conformity with learning material, the validation results obtained a rcount value of 0.81 which shows calorimeters from various simple materials in accordance with the national curriculum, so that it can be used in chemistry learning of thermochemical material, especially in practicum

activities [11]. This is in accordance with that stated that the teaching aids that are made must be in accordance with the subject matter so as to make it easier for students to understand the subject matter [33].

In the practical aspect, the validation results have a calculated value of 0.83 and the feasibility results have a percentage of 97.22% indicating that calorimeters from various simple materials are practically used. Simple laboratory standard calorimeters are still used manually so stirring the solution in the calorimeter is not constant. In addition, the tip of the ring-shaped stirring rod makes the calorimeter stirring less evenly distributed. Therefore modifications were made to the calorimeter design of a variety of simple materials, which is equipped with an automatic stirring design as shown in Figure 1 so that a simple calorimeter design was formed as a result of the modification as shown in Figure 2 .

The existence of an automatic stirrer is characteristic of calorimeter products from a variety of simple materials because the existence of an automatic stirrer makes a calorimeter from a variety of simple materials easy to use. In addition, calorimeters from a variety of simple materials are easily treated properly because the components are easily removable. This is in line with the fact that using technology makes things easier [34] .

In the aspect of display and durability of the tool, the results of the validation have a calculated value of 0.75 and are supported by the feasibility results with a percentage of 87.50% so that it shows that calorimeters from various simple materials have a good appearance and durability so as to attract



students' interest in the products used and the product can be used for a long time.

The making of calorimeter from various simple materials is adjusted to the calorimeter design that has been made as shown in Figure 2 so as to create a product that has a good appearance. Appearance becomes the main thing as a support for a work that can be enjoyed [35]. In addition to the props that have a good display can increase the attractiveness of students so that students do not get bored when using props [21].

By using various simple materials obtained from used goods in the manufacture of calorimeters from various simple materials, the product has good durability. Simple material used as a calorimeter vessel using material that does not leak easily. In addition, the components of an automatic stirrer which are protected by a black box make the calorimeter from various simple materials not easily damaged. This is in accordance with that stated that props must have a good tool durability intended so that props are not easily damaged and can be used in a relatively long time [35].

In the aspect of tool efficiency, the results of the tool validation have a calculated value of 0.81 and the feasibility results which obtained a percentage of 97.22% indicate that a simple calorimeter is made efficiently. Simple calorimeters available in laboratories are relatively expensive. To overcome this, a simple calorimeter can be made using a variety of simple materials that have a price that is everyday life so as to produce an efficient product. This is in accordance with the stated that props can be created at a cost that is affordable and easily obtained [32].

In the aspect of tool safety, the validation results have a calculated value of 0.75 and are supported by the feasibility results with a percentage of 100% so that it shows that calorimeters from various simple materials are safe to use and simple materials used are not dangerous [33].

The calorimeter components of various simple materials are designed with safety considerations for students by using tools and materials that are non-toxic and harmless to humans as well as the environment in accordance with the green chemistry approach. Green chemistry studies include concepts and effective approaches to anticipate environmental pollution [24], [36].

## CONCLUSION

The results of calorimeter optimization from various simple materials (styrofoam, paper, plastic, melamine, PVC and bamboo pipes) in determining the calorimeter heat capacity and the change in neutralization enthalpy obtained the calorimeter accuracy value between 78-97%. The highest accuracy is obtained by bamboo calorimeter and the lowest accuracy is obtained by styrofoam calorimeter. The validation test results of 0.78 and the feasibility test results of 94.49% indicate that calorimeters from various simple materials are feasible and ready to be used as learning media.

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