Introducing Elephant's Toothpaste Experiment in Teaching Chemical Reaction for Junior High School Students

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Abstract

In Junior High School level, the integrated science lesson explores about simple science. It learns about the basic concept which consists of three subjects, i.e. chemistry, physics, and biology. In fact, many students are not interested in studying integrated science since most of them consider it as a difficult lesson. In their point of view, learning integrated science is usually considered as the abstract objects which can not be seen, for example, the reaction rate concept. However, the utilization of the natural phenomena in learning integrated science is possible to make the students being interested in studying integrated science. One of the examples of chemical reactions which can be demonstrated interestingly is the Elephant's Toothpaste experiment. This experiment shows the reaction between Hydrogen Peroxide and Potassium Iodide that produce tangible products of an explosion that has been modified into a foam.The purpose of this study was to introduce the experiment to the students and to help them in the understanding of chemical reaction in a fascinating way. The use of Hydrogen Peroxide (H_2O_2) in the experiment is an underlying theme to introduce fundamental concepts in reaction rate to the junior high school students with K-13 Curriculum. The results obtained indicate that the experiment of Elephant's Toothpaste improves the understanding of the students on chemical reactions.

Keywords: Elephant's Toothpaste, chemical reaction, Potassium Iodide, Hydrogen Peroxide

Introduction

Indonesia has admitted the importance of the right to education. It is shown by the adoption of the right to education into the Constitution and Statutes, and also the ratification of international human rights instruments, as well as creating education program projects by the government (Manan, 2015). Based on the history of Indonesian curriculum, the 2006 curriculum describes that the central education authority developed general competencies and minimum content outlines. The individual teachers developed their subject curriculum, including formulating learning objectives, selecting content, teaching strategies as well as developing learning evaluations independently. This curriculum stressed the achievement of standardized competencies that students had to achieve, and the development of life skills to prepare graduates to survive in life (Taber, Taylor, & Turner, 2017). Nowadays, the Indonesian schools are employing the 2013 curriculum which the method is students as the center of learning, and the teacher acts as a facilitator. The first step in designing a curriculum for continuous professional development is an assessment of teachers' needs. Teacher needs are assessed by planning and implementing of in-service training programs. The assessment will be systematic, and teachers can obtain the benefit from the program. A careful planning and implementation of professional development can build strong correlations between teachers' knowledge and students' achievement (Darling-Hammond, Chung Wei, Andree, Richardson, & Orphanos, 2009).

Science, as a school subject is gaining the attention to be developed and to be the main prominence in the school curriculum. There are many science curriculum innovations world wide, and so in Indonesia, there are several changes in the science teaching of the content in different levels of education. Science learning is always conducted with experiments, observations, and discoveries. It provides the development of skills of students asking questions and making investigations, making a hypothesis, an inference of results of experiments to students (Açıkgöz, Kaygusuz, & Öncül, 2004). Laboratory method is often used in science, and it is targeted that students do trial and error activities. Therefore, the laboratory applications are an integral part of science (Orbay, Özdoğan, Öner, Kara, & Gümüş, 2003). The success of science programs depends in large part on the classroom teachers. They constitute the most important agent in the on going exercise to revolutionize the teaching and learning of science (Osuolale, 2014).

This study aimed to introduce the chemical reaction that can help the students more interested in studying integrated science with a demonstration about the science project; it is elephant's toothpaste experiment. Elephant's toothpaste is a new experiment that can help students understand chemical reaction easily.

Materials and Methods

Materials

The reagent that used in this experiment were Hydrogen Peroxide (H_2O_2), a yeast of bread "Fermipan", Potassium Iodide (KI), distilled water, artificial food colorants, and liquid dishwashing soap. The instruments used were drop pipette, funnel, the big bottle glass, measuring glass, Beaker glass, and stirring glass.

Preparation of Hydrogen Peroxide (H_2O_2) Solution

This experiment needed three variations of Hydrogen Peroxide (H_2O_2), i.e. 25%, 50%, and 75%. Variation concentration of Hydrogen Peroxide could be made by mixing up pure Hydrogen Peroxide (H_2O_2) with distilled water. The total volume of each concentration was 50 ml.

Preparation of Catalyst

Two catalysts were used in this experiment. They were Potassium Iodide and "Fermipan," the bread yeast. Potassium Iodide and Fermipan have the powder form. The reaction rate would run quickly by the addition of catalyst which has a larger surface area. Therefore, the catalyst in this experiment should be dissolved along with distilled water. The dissolution of the catalyst by distilled water was carried out by dissolving 3 g/1 teaspoons of catalyst (Potassium Iodide powder or Fermipan powder) in 10 ml of distilled water.

Experimental Methods

At first, Hydrogen Peroxide (H_2O_2) solution was poured into the bottle; then, the food colorants were added into the bottle through the bottle wall with other motifs. The result of this experiment was most beautiful by using the variation of food colorants. Next, the addition of liquid dishwashing soap using a pipette to the bottle. Then, 3 ml Potassium Iodide solution was added quickly using a funnel. The reactions rate was measured by observing the reactions rate that occurs in this session. The experiment was repeated by the variation of Hydrogen Peroxide (H_2O_2) solution concentration. Next, the second experiments used Fermipan as a catalyst using the same methods. Lastly, the results of all experiments were concluded by the students.

Hazards and Hazard Mitigation

Hydrogen peroxide (H_2O_2) was an oxidizing agent, even at low concentrations, that could rapidly decompose to released oxygen. Hydrogen peroxide should be kept away from flammable places and other reducing agents. H_2O_2 concentrations used in this activity range from 25-75%. Hydrogen peroxide (H_2O_2) could irritate the skin and eyes; the students could wear a latex glove and safety glasses during the activity to protect them from evaporation of H_2O_2 at various concentration. The apparatus was designed with several safety features to mitigate these hazards (Cybulskis, 2016).

Result and Discussion

Description of Potassium Iodide (KI)

Potassium Iodide (KI) is an inorganic compound and has a simple molecule structure, a salt of stable iodine. The ionic that contains potassium iodide molecule are ion K^+ and ion I^-. Potassium Iodide (KI) is comprised of 23.55% potassium and 76.45% iodine (Merck Index, 2006). This salt is the most commercially significant iodide compound. Potassium Iodide (KI) is produced industrially by treating potassium hydroxide with iodine (Lyday, 2000). Saturated Solution of Potassium Iodide (SSKI) should be stored in tight, light resistant containers at a medium temperature around of 15–30°C. Crystallization may occur following exposure to cold. The process of dissolve crystals with warming and shaking the solution of Potassium Iodide. The color of Potassium Iodide solution in water is bright yellow, and the color of Potassium Iodide in the air is white. If the solution of Potassium Iodide turns brownish yellow, it should be discarded (Iffat Hassan, 2012).

Potassium Iodide crystallizes in the sodium chloride structure, hexahedral crystals. Potassium Iodide is less hygroscopic than sodium iodide, making it easier to work. Potassium iodide is stable in dry air but slightly hygroscopic in moist air. Aged and impure samples are yellow because of oxidation of the iodide to iodine (Lyday, 2000).

$$4KI + 2CO_2 + O_2 \rightarrow 2\ K_2CO_3 + 2\ I_2$$

A small amount of iodate may be formed. Light and moisture accelerate the decomposition. The aqueous solution also becomes yellow in time due to oxidation, but a small amount of alkali prevents it (Merck Index, 2006).

Description of Hydrogen Peroxide (H_2O_2)

Hydrogen peroxide (H_2O_2) is a shelf-stable chemical reagent that is commonly stored for household use; however, its rate of decomposition can be accelerated by orders of magnitude with various catalysts such as sodium iodide (NaI), potassium iodide (KI), platinum, and the enzyme catalase. The catalytic decomposition of H_2O_2 into water and oxygen is:

$$2\ H_2O_2 \rightarrow 2\ H_2O + O_2 \qquad \Delta HR° = -98.2\ kJ\ mol-1$$

It is a widely used reaction in chemistry demonstrations the elephant's toothpaste experiment to demonstrate fundamental concepts in kinetics and catalysis of the reaction rate. The including catalyst and peroxide reaction will orders reaction enthalpy, and activation energy (Cybulskis, 2016).

Hydrogen Peroxide can be chemically produced from deoxygenated compounds or by the electrolysis of sulphuric acid or sulfates at a platinum anode. A conventional electrochemical technique uses the cathodic reduction of oxygen with potassium hydroxide as the electrolyte. Recent work has described peroxide production in a three-electrode cell with the additional of Fenton reagent. However, the challenge consists in producing hydrogen peroxide, by water electrolysis in a two-electrode cell without chemical addition (P. Drogui, 2001).

Determining of Hydrogen Peroxide (H_2O_2) concentrations can do by cerium sulfate oxidation of peroxide using ferrous orthophenonantroline as an indicator (P. Drogui, 2001).

$$2\ Ce^{4-} + H_2O_2 \leftrightarrow 2\ Ce^{3+} + O_2 + 2\ H^+$$

A WTW-SL 340 oximeter gave oxygen concentrations; whereas the dissolved organic carbon (DOC) was measured with a TOC meter Shimadzu TOC 5000. Turbidity was obtained with a Hach DR 2000 turbidimeter. 254 nm absorbance was measured with a Jasco V-530 spectrophotometer. Most other parameters, particularly microorganism concentration and chemical oxygen demand (COD), were determined in conformity with Standard Methods (American Public Health Association, 1995).

The experiment's aim is to determine the effect of reagent and catalyst concentration on reaction rate. The use of Hydrogen Peroxide (H_2O_2) solution with various concentration is to know the effect of concentration. The use of Potassium Iodide powder is to act as a catalyst so we can know the effect of the catalyst on the reaction rate. In this case, the concentration of Hydrogen Peroxide (H_2O_2) and Potassium Iodide solution is an independent variable, while the rate of reaction rate is a dependent variable. The use of soap is intended to prevent the occurrence of an explosion in the reaction due to the reaction of a solution of Hydrogen Peroxide (H_2O_2) with a powder Potassium Iodide that arises according to the theory of explosion. The explosion can be converted to a harmless foam with the function of the liquid dishwashing soap. Meanwhile, the use of food coloring is intended to beautify the appearance of foam reactions to be more attractive and can look like the real toothpaste.

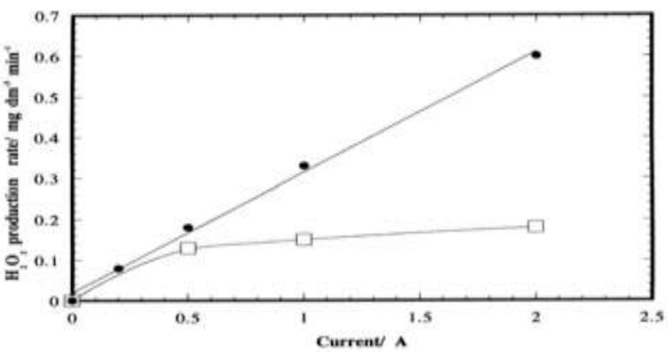

Fig.1 Hydrogen peroxide production rate against intensity.

Key: (□) unit 1 and (●) unit 2 (American Public Health Association, 1995)

The catalyst in this chemical reaction experiment was used to speed up the rate of reaction in the elephant's toothpaste experiment. The surface chemistry of the potassium iodide (KI) heterogeneous catalyst is the subject of some investigations to explain the great activity of the photocatalysts. It is recognized that potassium iodide (KI) exists in several different forms on the explosion it is a foam as a result of this experiment, with the specification depending on the potassium iodide (KI) content and catalyst pretreatment conditions (J. N. Nian, 2006). Potassium Iodide (KI) is a powerful catalyst in nature, and its use should not be unattended. On the other hand, potassium iodide (KI) heterogeneous catalyst is also found suitable for iodide reductions (X. Yau, 2014). The kinds of catalyst that can be used for this experiment is the bread yeast, Fermipan. Fermipan, as a brand of bread yeast, is a selected substitute for the catalyst in the elephant's toothpaste experiment. Fermipan can substitute potassium iodide because it can react with potassium iodide catalyst with a lower reaction rate and it is safe to be used. Therefore, the reaction rate in Elephant's Toothpaste experiment can still take place. The use of these two types of the catalyst also has the purpose of utilizing variations of the catalyst type in testing the rate of this reaction.

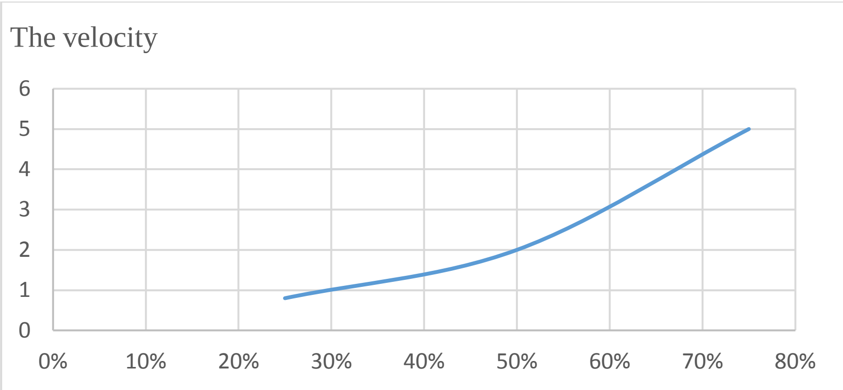

Fig 2. Potassium Iodide as a catalyst

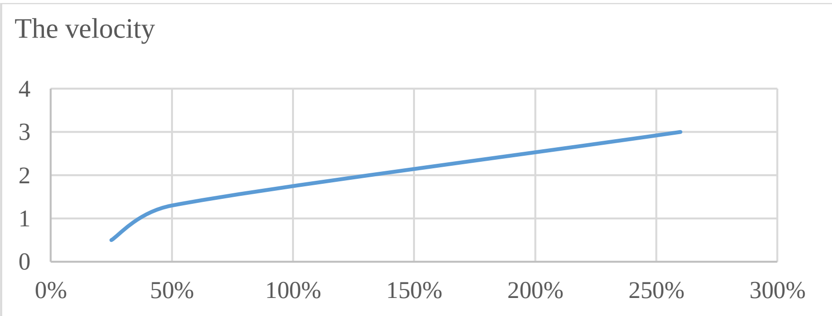

Fig 3. Fermipan as a catalyst

The experiment using 75% Hydrogen Peroxide (H_2O_2) gave the fastest reaction rate which resulting in much foam comparing with the previous experiments. The result from the elephant's toothpaste experiment which uses potassium iodide as a catalyst shows that the more the concentrations of reagents in the form of Hydrogen Peroxide (H_2O_2) solution is used, the faster the reaction rate will be. The result of the experiment happens because the more the reagent concentrations are used, the larger the number of reacting molecules will be. Due to a large number of molecules, the possibility of collisions between reactant particles become greater than before. Therefore, the reaction rate will be fast in this condition.

Fig 3.1 The fastest reaction rate use H_2O_2 75 % with KI

Fig 3.2 The lowest reaction rate use H_2O_2 25 % with Fermipan

(Private documentations)

The experiment of elephant's toothpaste using Potassium Iodide reactions took place very quickly, and the resulting foam was plentiful. In this experiment, the Potassium Iodide powder acts as a catalyst. The catalyst works by lowering the activation energy (Ea). Before the catalyst is added, the reaction has a high activation energy (Ea) which requires more energy for the reaction to take place. When the catalyst is added, the reaction has a low activation energy. Therefore, the reaction can be more easily reached because it does not require large energy to achieve the activation energy (Ea) of the reaction. The results from elephant's toothpaste experiment showed that the model which best fits the relationship between the defined Arrhenius parameters is a logarithmic type correlating the activation energy (Ea) to the Arrhenius temperature TA (K) because when reaction rate occurs temperature increase and the activation energy descends. Reaction rate in this experiment can increase because using potassium iodide and Fermipan as a catalyst and their can descend the activation energy (Ea) (Messaâdi, 2015).

This experiment shows the decomposition of hydrogen peroxide (H_2O_2) catalyzed by potassium iodide (KI). According to the theory, Potassium iodide (KI) functions as a microbicide which is used in emergency drinking water purification/disinfection, fresh food sanitization, food-contact surface sanitization, hospital surface disinfection, and commercial and industrial water cooling tower systems (EPA RED, Case 3080, 2006). The statements explain that potassium iodide has the position as a catalyst in the experiment of elephant's toothpaste experiment. The catalytic performance of hydrogen peroxide (H_2O_2) heterogeneous catalyst is mainly determined via the particle size and properties of the support (F. Porta, 2000). Hydrogen Peroxide (H_2O_2) solution can indeed break down into water and oxygen gas; therefore, this reaction is prolonged to be felt or measured. The reactions that occur are:

$$2\ H_2O_2 \rightarrow 2\ H_2O_{(l)} + O_{2(g)}$$

In this experiment Potassium Iodide (KI) powder was used as a catalyst to speed up the reaction. The reactions that occur between hydrogen peroxide and potassium iodide as a catalyst is:

$$H_2O_2 + I^- \rightarrow H_2O + IO^-$$

$$H_2O_2 + IO^- \rightarrow H_2O + O_2 + I^-$$

The reaction that occurs show ion I^- from KI (Potassium Iodide) binds ion O^- from H_2O_2 (Hydrogen peroxide) and results in IO^-. Iod monoxide (IO^-) in hydrogen peroxide excess will bind with H_2O_2 and results in H_2O, O_2, and ion I^-. The effect of this reaction is an explosion, the blast that has a foam form is a result of the reaction between H_2O and liquid dishwashing soap. The oxygen that decomposes from the system causes the soap or detergent foam to get stronger and more so that the foam will erupt out. Steam coming out of the foam indicates that the reaction that occurs is an exothermic reaction or heat release.

The experiment with "Fermipan" as a bread yeast and 25% hydrogen peroxide (H_2O_2) solution showed a slow reaction rate and resulted in the small amount of foam. The foam produced by the reaction between 75% hydrogen peroxide (H_2O_2) and "Fermipan" was not more than previous experiment using 50% hydrogen peroxide (H_2O_2) and potassium iodide. Therefore, the highest foam resulted from the reaction of 75% hydrogen peroxide (H_2O_2) with potassium iodide.

The experiment of mixing hydrogen peroxide (H_2O_2) with "Fermipan" shows that the more concentration of hydrogen peroxide (H_2O_2) used, the faster the reaction rate will be. The reason is the more reagent concentrations, the number of reacting molecules is also significant. With a large number of molecules, the greater the possibility of collisions between reactant particles; then, the reaction rate will be high giving the fastest of the response rate in this experiment. In this case, the solution of Fermipan acts as a catalyst. The catalyst works by lowering the activation energy (Ea). Before the catalyst is added, the reaction has a high energizing energy which requires more energy for the reaction to take place. When the catalyst is added, the reaction has a low activation energy. Therefore, the reaction can be more easily reached because it does not require enormous energy to achieve the energizing energy of the reaction.

Activation energy is strictly combined with the kinetics of the chemical reaction. Activation energy is the amount of energy that ensures to make the reaction can happen. Usually, common sense is that higher temperature causes the two molecules to collide with each other more fastly. Therefore, the concept is that the rate of a chemical reaction is directly proportional to the temperature and the effect of the temperature on the rate of chemical reaction is calculated by the Arrhenius equation (Mukhtar, Shafiq, Khan, Qadir, & Qizilbash, 2015). The activation energies can calculate by Ozawa method, and Coatse-Redfern method is close for cellulose, Friedman method is the double with acceptable values of the correlation coefficient, Kissinger method, and OFW method (Abderrahim, Abderrahman, & Aqil Fatima, 2015).

Based on this study, the students showed their passion with outdoor's experiment to understand the integrated science lesson. The student can explore phenomena and also analyze much information from their environment. The application of elephant's toothpaste experiments supports experiments that students can perform in integrated science learning according to the curriculum applicable in Indonesia is Curriculum 2013. Learning to junior high school in the curriculum 2013 requires students to be active in learning by doing various experiments. The elephant's toothpaste experiment is used as an innovative work of teachers to teach science in grade VII junior students on elemental topics, compounds, and a mixture of sub-topics of "chemical reactions and physical reactions." The experiments of elephant's toothpaste demonstrate the example of a chemical reaction with the characteristics of a non-reversible reaction, yielding a new substance, and a visible change of being. Improving student's understanding using experimental demonstrations of elephant's toothpaste makes it easier for students to understand how the real example of a chemical reaction occurs.

Fig 4.1 The process of demonstration Elephant’s Toothpaste experiment
(Private documentation)

Fig 4.2 The student's interest with this demonstration
(Private documentation)

The demonstration experiments of elephant's toothpaste are done outside the classroom in an orderly fashion, and the students are interested in following the stages of experiments. According to the Fig 4.2, the student showed that she was interested in the result of this experiment. Furthermore, when the demonstration have been holding the students was very interested. It can be seen from many applause from the students when the first experiment is doing. The students want to try the experiment with their group again quickly because they appreciated with this experiment.

Elephant's toothpaste experiment was developed to promote scientific learning in an informal environment among curriculum 2013 students by having them measure H_2O_2 decomposition rates, compare rates among different reactor units with different H_2O_2 concentrations. During the elephant's toothpaste experiment, students participate in the practices of planning an experiment, carrying out an investigation, and analyzing and interpreting experimental data. By using H_2O_2 decomposition on Elephant's toothpaste experiment as the central theme for these outreach events, we can make connections across the physical sciences (chemical reactions), life sciences (catalase enzyme), and applications of science (reactor design).

Elephant's toothpaste experiment is demonstrating how catalysts facilitate chemical reactions, by showing how chemical energy is released upon H_2O_2 decomposition. The types of experiments performed in the versatile laboratory apparatus can be tailored to teach concepts in catalysis and kinetics to students of widely varying chemistry background and experience. For example, more advanced experiments can be performed with different types of catalysts (KI, Fermipan), or at various temperatures with the same catalyst, to teach students about the concept of an activation barrier for a chemical reaction and how catalysts accelerate reaction rates by lowering this activation barrier.

The author proposes Elephant's toothpaste experiment could be expanded into a laboratory experiment for a junior high school that aligns with the scientific practices. We have successfully used this activity as an informal science education tool that allowed students to plan and carry out investigations, to analyze and interpret data, and to obtain, evaluate, and communicate results.

Conclusion

Improving the understanding of chemical reaction with elephant's toothpaste experiment for junior high school is effective. The students showed their passion and their ability to understand the concept easily after the demonstration of the experiment. It can be seen from the post-test results. Based on their feedback, it indicates that they became excited and happy in learning science especially chemistry by witnessing the demonstration and performing real experiments. Their suggestions for improvement of this demonstration focused on providing more opportunities for activities.

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