

ENJOY LEARNING

— Deepened Application of System Thinking in High School Chemistry Teaching Practice

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The paintings of impressionists often leave us a profound impression as follows: when taking a close look at them, we find those strokes, of which a piece of painting consists, only are numerous fine points of different colors. However, as we gradually stand back, we realize that, a certain change of colors forms and a sense of dynamics is also presented due to these inter-related fine points, which consequently turn into exquisite art works. Such a change of viewing angle brings us corresponding experience of various feelings as well as enjoyment of the beauty. This relation of the part and the whole shown in the static two-dimensional world tells us that the angle from which we view something determines what we can see, and also how we can understand it.

This phenomenon, to a certain extent, inspires us that, to know the world cannot merely rest upon the knowledge of each particular thing or practical process. What is more important is to pay attention to the interrelation between things as well as processes in addition to the individual knowledge mentioned above. Only by doing so, we may have clear and exact mastery of the complexity of the material world and the social environment. Furthermore, this attitude can help us to obtain abilities to foresee the developing trend of any practical problem when we face it, and subsequently to make correct estimation and decisions.

System dynamics and System Thinking are illuminating in that these knowledge encourages people to form a clear thinking, lays the foundation for them improving communications, and facilitates them obtaining extraordinary thinking and courage, thus gradually helping people develop a philosophy “to harmonize with the complicated world in which they live”.

In the teaching practice during the past two years, by incorporating chemistry teaching, we have carried out research and discussions on related problems from a systematical viewpoint mainly with the help of the software STELLA, the tool of system dynamics. Students have confirmed their own hypothesis by doing experiments, conducting observation, analyzing and imagination, as well as computer simulation. They have thoroughly enjoyed the pleasure brought in the exploration of new knowledge and also achieved more satisfactory learning results.

Prior to this paper, we shared with the present honored specialists our experiences on the simulation of “ammonia-synthetic reaction” kinetics and system behaviors in a “redox reaction”. This time, we still hope to elaborate our understanding of system dynamics and the progress made by our students in such a learning process by taking as examples some concrete teaching processes.

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Case 1: Mutual effect between factors in a chemical reaction process

The rate of a chemical reaction, from the viewpoint of the knowledge on chemistry, is affected by multiple factors, such as the concentration, pressure, temperature, catalyst, luminance, size of solid particles.

In our teaching process, we ask students to investigate the effect of various factors on the rate of a chemical reaction. They do this by conducting a set of comparison experiments under the controlled conditions. For example, some of these experiments are about the reaction rate comparison between different reactant concentrations under the isothermal condition, or about the same concentration of the reactant under different temperatures, or about the influences of catalyst under the isothermal condition and the same concentration.

During the H_2O_2 decomposition experiment in the presence of MnO_2 as catalyst, most of students would add MnO_2 into the H_2O_2 aqueous solution as usual, and find a great volume of gas generated immediately afterwards. The phenomenon shows that MnO_2 is one of catalysts that can promote decomposition of H_2O_2 , so the requirement for the experiment is considered to have been met.

Some students, however, in the continuous observation of the experiment process, are surprised to encounter such a phenomenon that the rate of H_2O_2 decomposition remains smooth in the initial stage. Soon afterwards, along with continuation of the reaction, the rate gradually increases and reaches a peak value, and finally, the rate gradually drops (figure 1). Such an experience of change of oxygen-generating rate in the experiment may be illustrated in figure 2. This is a typical phenomenon of Overshoot and Collapse.

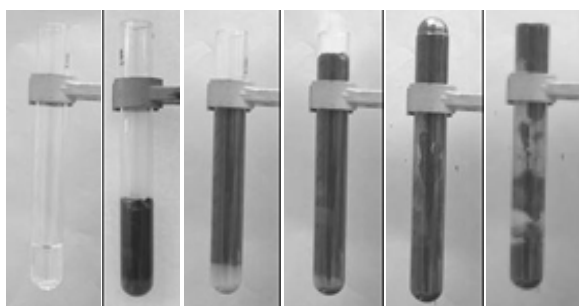


figure 1

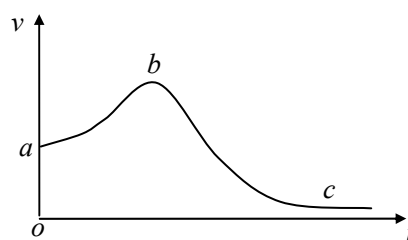


figure 2

The similar phenomenon may be found in the experiment using FeCl_3 as catalyst. In view of this, the phenomenon may be explained as an inherent one in the decomposition process of H_2O_2 , having nothing to do with catalyst's property.

Students conduct their analysis by focusing on factors affecting the reaction rate. That is, the concentration of H_2O_2 gradually decreases along with continuation of the reaction. And during the later period of the reaction, the rate gradually declines due to increasingly lower concentration of the reactant. However, existence of the peak value shows that there is another factor—temperature, which is also affecting the progress of the chemical reaction simultaneously.

This analytical and judging process is consistent with the phenomenon of gradual temperature elevation that students observed in the text-tube experiment.

Why does this happen?

Using STELLA, I have carried out a simulated research along with students

Based on assumption that this is a first order reaction, we have initially established a model in which the concentration of the reactant affects the reaction rate (Figure 3).

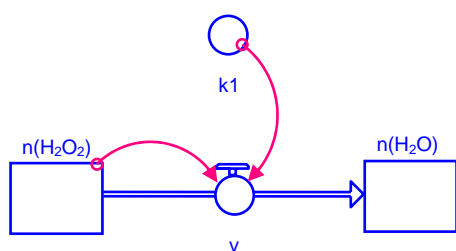


Figure 3

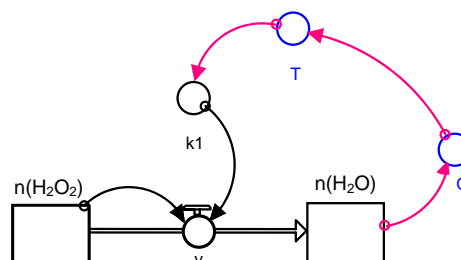


Figure 4

In consideration of the fact that due to decomposition of H_2O_2 as an exothermic reaction, elevation of the temperature of the H_2O_2 aqueous solution accelerates the rate of the chemical reaction. Thus, the relevant model is revised accordingly: heat released in the reaction (Q) is directly proportional to the amount of water generated in decomposition of H_2O_2 . In the meanwhile, as temperature of the solution (T) rises, elevation of temperature will directly affect the rate of the chemical reaction (Figure 4). In Figure 4 there are two feedback loops. The $n(H_2O_2) \rightarrow v \rightarrow n(H_2O)$ is the negative loop and $v \rightarrow n(H_2O) \rightarrow Q \rightarrow T \rightarrow k_1 \rightarrow v$ is the positive loop. It is this reason that brings on the phenomenon in Figure 2.

It is hypothesized that the mass of the solution is m . For a fixed amount of H_2O_2 , the larger the value of m is, the lower the concentration of the solution will be. The mass of the system will decrease along with continuation of the reaction and liberation of oxygen (Figure 5).

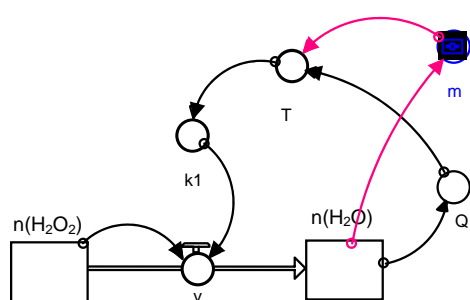


Figure 5

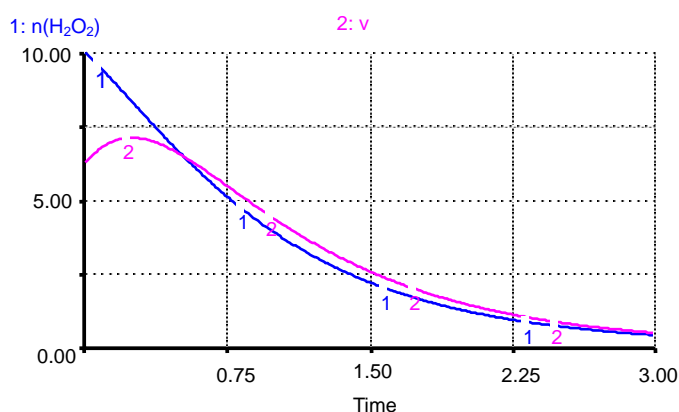


Figure 6

In Figure 6, the curve 1 indicates the change regarding the amount of (H_2O_2) in the reaction; the curve 2 shows the changing rate of the reaction in which the H_2O_2 is consumed. There is a linear relation between the consumption of H_2O_2 and the generation of oxygen. An anticipated peak value appears in the graph of reaction rate.

At the same time, however, a new problem is laid to the front of us. Some students will ask: why no peak value of the reaction rate is found in the experiment?

They find that, through their own discussion, if initially the concentration of the reactant is lower, the reaction rate will also be slower, and the heat generated in unit time will consequently be lower too. The existence of a larger amount of heated materials in the reaction system results in the minor effect of temperature on reaction rate. The abnormal peak value of reaction rate will gradually disappear.

On the basis of the simulation experiment, the rule determining the appearance of the peak value in the rate curve is investigated by changing the value of m using a sliding rod simulator, and the result shows it is in consistence with students' presupposition (Figure 7).

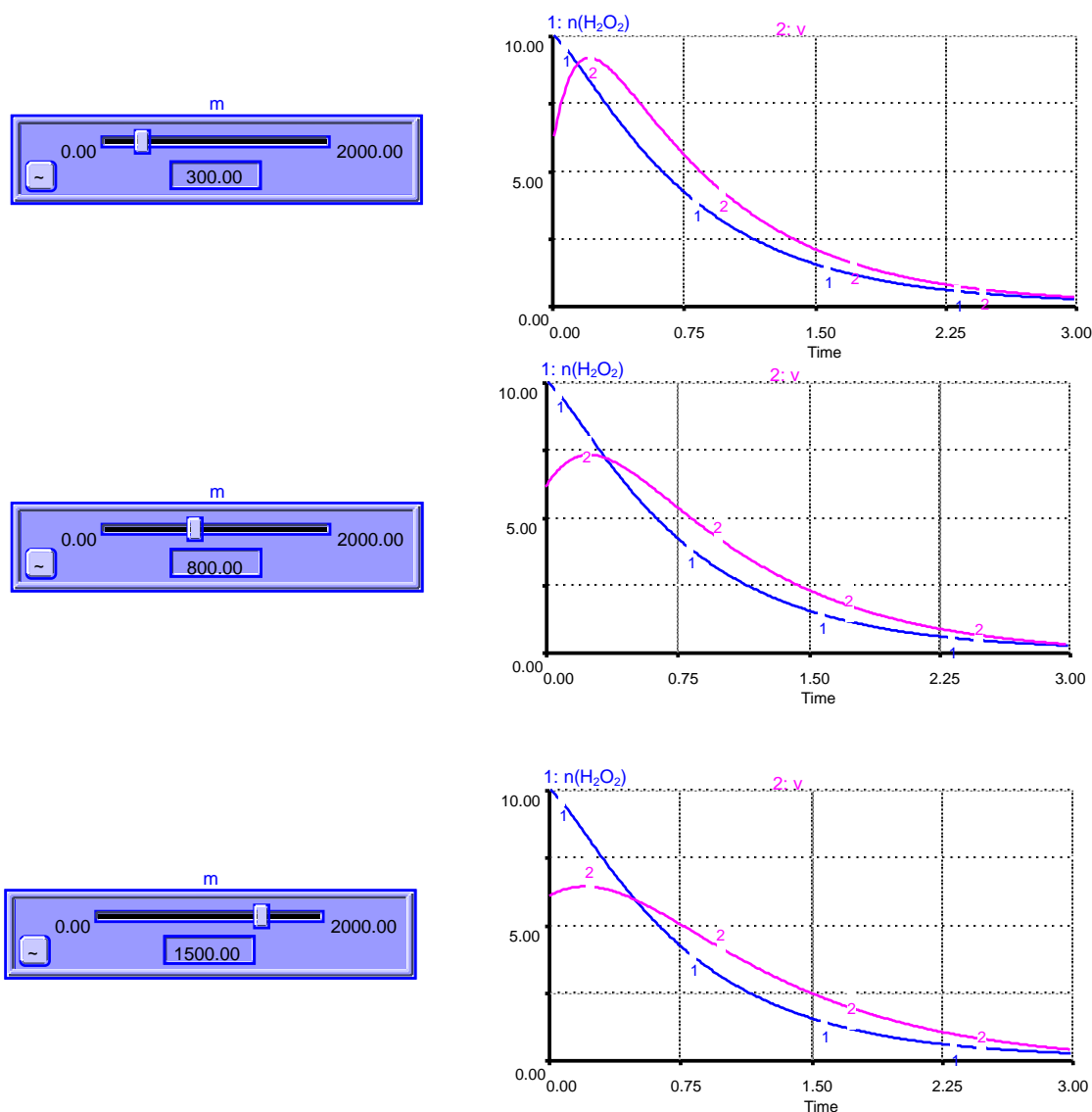


Figure 7

What makes this experiment significant is that conclusions from it are all verified in subsequent chemical experiments.

The process of observation, guessing, and verifying activates students' curiosity and their thirst for deeper understanding. At the same time, it brings them the pleasure of exploration.

Why is the change of reaction rate observed by us in the practical experiment so radical, and that shown in the simulation experiment in the graph above relatively smooth?

During the discussion, students realize that, in observation of change of oxygen amount, they have only given attention to volume change of oxygen, but neglect the effect of temperature on the volume. In other words, its volume will expand when oxygen is heated. If the model is revised as follows (Figure 8), the volume change of oxygen in unit time can be observed with the passing of time.

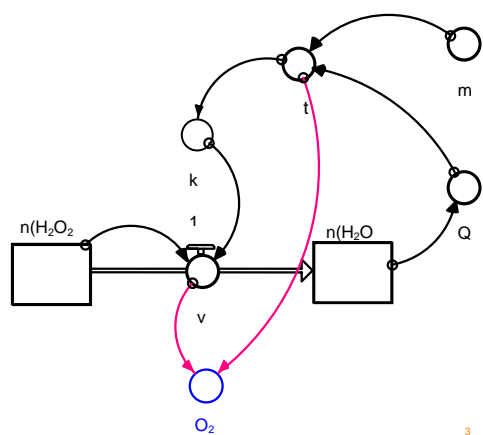


Figure 8

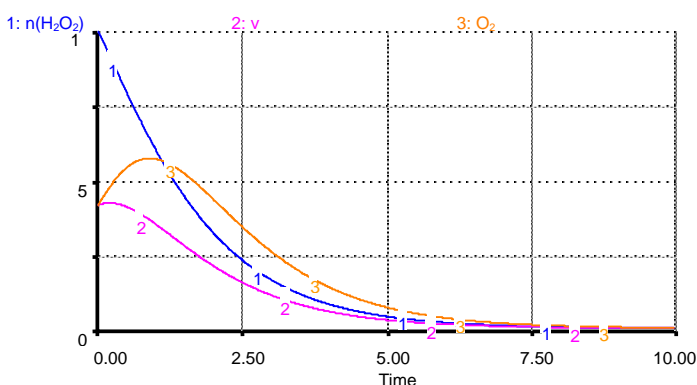


Figure 9

The curve 3 with the peak gets steeper now (Figure 9).

However, a relatively smooth curve does not appear in the initial stage of reaction. As the students are lacking the concept of the delayed effect, a teacher shall explain the universality of the phenomenon with metaphorical descriptions. If taking into account the delayed effect of the temperature on the reaction rate, the corresponding model may be illustrated as the form in Figure 10.

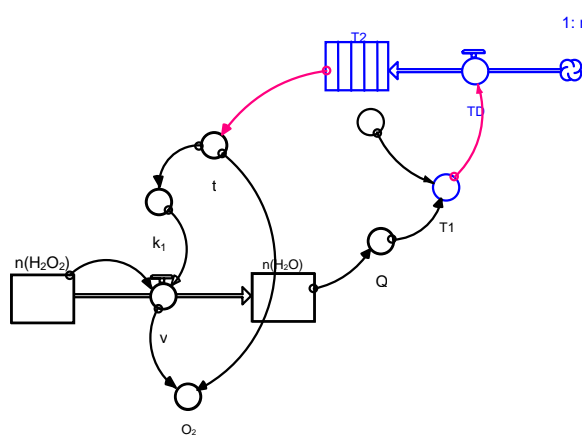


Figure 10

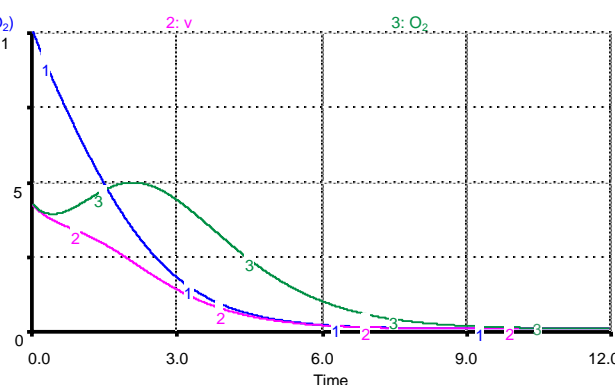


figure 11

At this moment we may observe the simulation result (the curve 3 in Figure 11), which is getting closer to the practical situation.

In the course of the simulation experiment, what is significant is not to get a final result, but a

way of thinking that students have developed to analyze complicated things, and the ability to understand the inner link and manifestation of objective things in the process of gradually approaching the reality.

Based on the exiting knowledge, some students worked out an experiment scheme in their spare time to measure the volume of oxygen generated in the same period of time e.g., within 10 sec. The methods proposed in the scheme include using a syringe or calculating effluent water to measure the volume of oxygen. Because oxygen collected has a higher temperature in the former case while it is cooler in the latter case, two groups of students find differences between the peak shapes plotted that illustrate the change of the oxygen-generating rate with passing of time. This phenomenon conforms to the result of simulation experiment.

Case 2: From “black powder” to “rocket propellant”

This is an experiment filled with curiosity, excitement and enthusiasm for students.

In the chemistry-teaching program for students of Senior Grade One (K10), gas mole volume is included. That is, gases of the same molecular quantity take the same volume. A gas of one mole, regardless of whatever it is, takes about 22.4 liters under the standard state.

In order to promote students’ understanding of the unique nature of gas, which completely differs from that of solid or liquid, we may start from the calculation of volumes of 1 mol of a substance in different states. The comparison of practically measured data may help students not only to develop the concept of gas molar volume, but also experience it by themselves. Following this, we are able to further explain the causes of the unique property of gas from the angle of arrangement and distribution of particles in a substance.

To help students consolidate the concept on conversion between the amount of a gas substance and its volume in the standard state, we keep reflecting whether the goal for students to learn the concept on gas molar volume is to establish a link between the values of related physical quantities; or whether we can have students achieve deeper understanding and inspiration while they are learning the above-mentioned knowledge.

The teacher designs the following teaching scene.

Black powder is one of four great Chinese inventions. Its main components are potassium nitrate, sulfur, and charcoal. The main reaction in its combustion and explosion may be put in the following equation: $2\text{KNO}_3 + \text{S} + 3\text{C} \rightleftharpoons \text{K}_2\text{S} + \text{N}_2 + 3\text{CO}_2$.

Problem 1 The table below shows the densities of the reactants. If all the components in black powder are formulated as in the above equation, and the average density of solid materials is taken to be $2\text{g} \cdot \text{cm}^{-3}$, calculate the volume ration of the powder materials before and after combustion-explosion in the standard state.

| Material | KNO_3 | S | C | K_2S |
|---|----------------|------|-----|----------------------|
| Density ($\text{g} \cdot \text{cm}^{-3}$) | 2.1 | 1.96 | 2.1 | 1.8 |

As shown in the reaction equation $2\text{KNO}_3 + \text{S} + 3\text{C} \rightleftharpoons \text{K}_2\text{S} + \text{N}_2 + 3\text{CO}_2$, if 2mol KNO_3 ,

1mol S and 3mol C can completely react, the total volume of the solid materials approximately is:

$$\begin{aligned}
 V_{Before} &= \frac{2M(KNO_3) + M(S) + 3M(C)}{\rho} \\
 &= \frac{2mol \times 101g \cdot mol^{-1} + 1mol \times 32g \cdot mol^{-1} + 3mol \times 12g \cdot mol^{-1}}{2.0g \cdot cm^{-3}} \\
 &= 135cm^3
 \end{aligned}$$

The 1mol N₂ and 3mol CO₂ are released in the reaction, and the gas volume in the standard state is:

$$V_{After} = 4mol \times 22.4L \cdot mol^{-1} = 89.6L = 89600 cm^3$$

The volume of K₂S generated in the reaction may be neglected. The volume ration of black powder before and after combustion-explosion in the standard state approximately is:

$$\frac{V_{After}}{V_{Before}} = \frac{4mol \times 22400 cm^3 \cdot mol^{-1}}{135 cm^3} = 663$$

Relevant scientific knowledge tells us that, the production of a great volume of gas in a narrow space will result in explosion. And if the gas produced in explosion escapes in a particular direction, this will lead to fireworks or may be used as propelling force of a rocket.

Students have enjoyed numerous times the scene of setting off fireworks, and that of launching space vehicles. Such experience may lead them to such knowledge that the main property of explosives or rocker propellants is the release of enormous heat in the reaction. However, what they sometimes neglected is the vast effect brought by the change of the physical state of materials in the reaction. In this sense, we may realize explosive operation in a low temperature provided that sufficient volume expansivity is available.

Problem 2 Let's continue our research by investigating the volume change of gas in explosion process of glycerin trinitrate explosive ($\rho=1.6g \cdot cm^{-3}$) invented by Alfred Nobel. The equation in the explosion is as follows:



If 4mol glycerin trinitrate is taken as the reactant, 29mol gases will be produced in the reaction. Thus, the volume ration before and after the reaction may be put as:

$$\frac{V_{After}}{V_{Before}} = \frac{29mol \times 22400cm^3 \cdot mol^{-1}}{4mol \times 277g \cdot mol^{-1} / 1.6g \cdot cm^{-3}} = 1145$$

All products after explosion of glycerin trinitrate are gases, so the explosive's volume expansivity is obviously larger than that of black powder. Students directly perceive the key reason why the brisance of glycerin trinitrate is far superior to that of black powder. Apart from that, they also become familiar with calculation of gas molar volume in the research process of the volume expansivity before and after combustion-explosion of the gunpowder. Even though black powder is one of symbols of ancient Chinese civilization that we feel proud of all the time, it has exposed its inherent limitation along with advancement of science and technology.

In this case, the teacher further questions the students:

How can they ensure more powerful impact force may be achieved from unit mass of the explosive?

The volume of the produced gas should be as large as possible.

How can the unit mass of the explosive produce as large volume of gas as possible?

First, change the reactants into gases as much as possible; second, the amount of the gas(es) production material should be as large as possible, that is, its relative molecular weight should be as small as possible.

Problem 3 Which are gases among the chemical substances we have learned? Which may be combustion-explosion products of gunpowder or rocket propellant?

The work to develop high-performance explosives or rocket propellants, in this mode, starts from the process to look for small molecules.

In their discussion, students enumerate a lot of gas molecules that they have studied, and put them in the molecular weight ascending order: H_2 , CH_4 , NH_3 , H_2O , CO , N_2 , O_2 , CO_2 , and others.

In consideration of ample oxygen with oxidation property in the Earth's atmosphere, which gases are not suitable to be the combustion-explosion product of a rocket propellant?

Obviously, H_2 , CH_4 , NH_3 , CO can't be the combustion-explosion product of rocket propellants because they are combustible gases.

Which molecules do you think will be contained in the product of rocket propellants? What is its optimum product?

There will be H_2O , N_2 , CO_2 , or other molecules in the combustion-explosion product of rocket propellants. From the viewpoint of relative molecular weight, water molecule shall be optimum, and any carbon-containing fuel that can produce CO_2 cannot be a favorable choice for rocket propellant.

Such analysis assists students in understanding the reason why human beings take liquid hydrogen and liquid oxygen as rocket propellants in the launching tests of space vehicles

Unfortunately, the compression-cooling system in the process of storing and transferring liquid hydrogen and liquid oxygen will increase the weight of the rocket, and this is a factor that has to be considered. For the convenience of storing and transportation, it is necessary to look for a type of fuel that can produce N_2 and H_2O in the course of combustion-explosion. For instance, combinations of N_2O_4 and N_2H_4 , or N_2H_4 and H_2O_2 , should be a good option.

Watching the launching of a rocket again, students find the red-brown gas (NO_2) emitted from the tail of the rocket (Figure 12). At the sight of this, they became proud of themselves from the bottom of their hearts for the above analytical process.



Figure 12

Some students keep asking further questions: when studying gunpowder or rocket propellants, why our first impression of them is the strong exothermal reaction? Will the heat released in the chemical change affects the performance of the rocket propellants? If so, to what degree?

To address these questions, we have carried out a simulated experiment with the help of the operation platform provided by “STELLA”. We have done this by taking the reaction process using N_2H_4 and N_2O_4 rocket propellant as an example.

On the basis of the chemical reaction equation: $2N_2H_4 + N_2O_4 == 3N_2 + 4H_2O$,

Taking 2 mol N_2H_4 and 1mol N_2O_4 as the fuel, we established a mathematical model in which the ration of the amount of N_2H_4 , and N_2O_4 consumed with N_2 , and H_2O produced in unit time is 2:1:3:4.

| reactant | inflow multiplier- N_2 | inflow multiplier- H_2O |
|----------|--------------------------|---------------------------|
| 1 | 6 | 8 |

The volume of the produced gases in the standard state can be calculated by adding the amount of the materials together and then multiplying V_m (gas molar volume), and a corresponding quantitative relation may be established using the amount of the materials which can produce water for energy change (Figure 13).

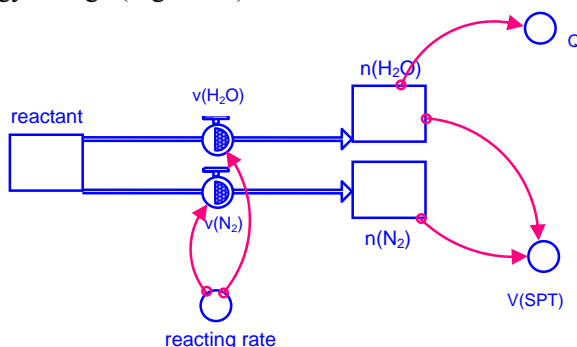


Figure 13

Heat released in the reaction will increase the temperature of gases. Supposing that the heat in the instant reaction process from combusting to jetting is completely used to heat gases, the rising of gas temperature may be reckoned by establishing a relation between the heat and the

molar heat capacity (C_p) of the gases in the isopiestic condition(Figure 14-1 and Figure 14-2).

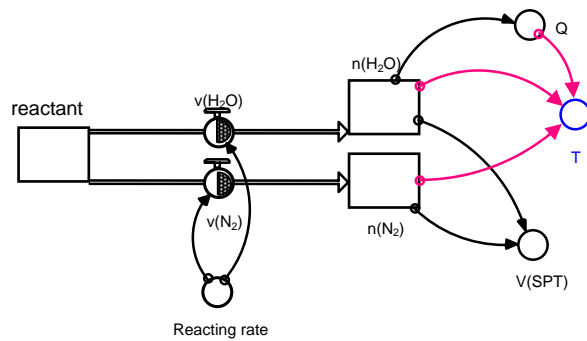


Figure 14

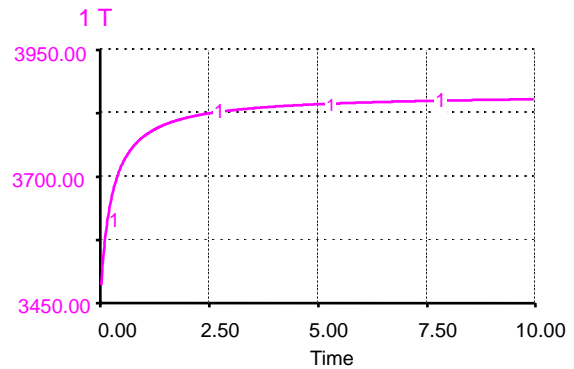


Figure 15

The data in the figure 14 show that temperature of the reaction system will gradually elevate along with continuation of the reaction.

The rising temperature of gases will expand the volume. According to the gaseous equation, it may be known that, under the isopiestic condition, the volume of gas will be equal to $V(SPT) \times T/298$ after it is heated. Therefore, we may compare the change of its volume when the gas is in two different conditions. In other words, changes occurring when heated [$V(T)$] or in the standard state [$V(SPT)$] can be illustrated in the following figures(Figure 16 and 17).

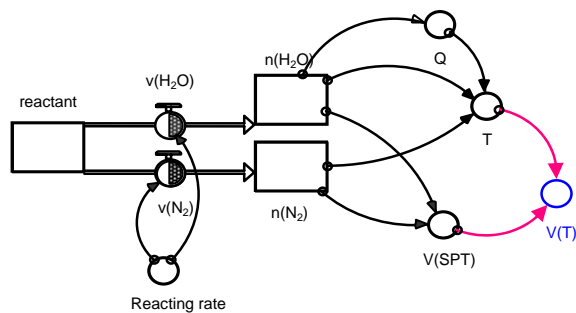


Figure 16

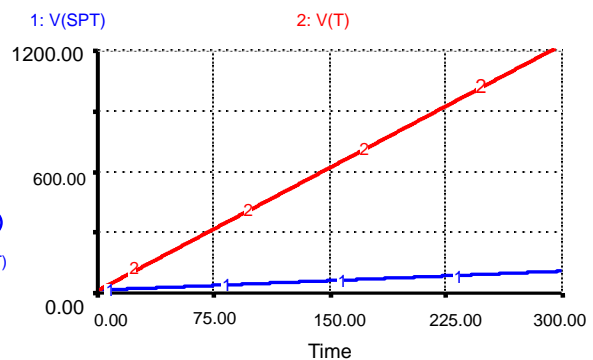


Figure 17

The result of running “STELLA” shows that the volume of the gas in a high temperature condition will increase to tens times of that in the standard state, along with continuation of the reaction and elevation of gas temperature for such exothermal reactions.

Does it consequently mean if the thermal expansion of the gas is the main reason to generate propelling force in a rocket?

The result shown in the figure 17 seems not to coincide with the conclusion from the previous inference, so it is hard for students to avoid puzzling regarding the matter.

If we calculate values of $V(SPT)/V(\text{reactant})$, and $V(T)/V(SPT)$ by analog computation on a P.C., what result will appear?

The following is the operation process (Figure 18 and 19):

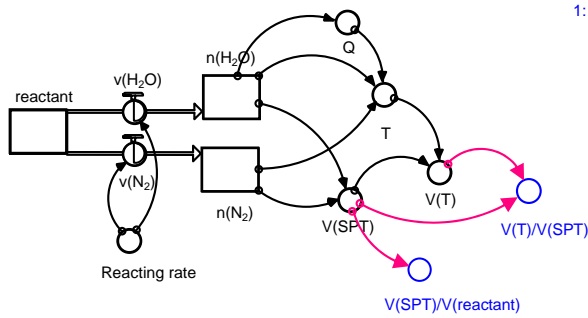


Figure 18

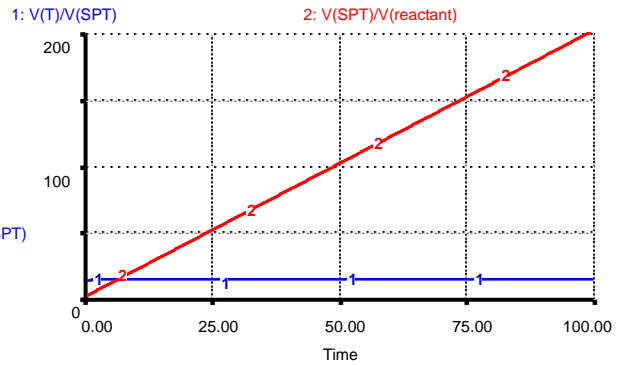


Figure 19

The result of analog computation shows again that the propelling force produced by the rocket propellant originates from two aspects: one is the state change of materials in the reaction, bringing expansion of gas volume, and this is the main propelling force to the rocket. Moreover, the energy released in the reaction is helpful for further expansion of gas volume, and it also has important effect on improving and strengthening propelling force of the rocket propellant.

Is there any relationship between expansion of gas volume and gas-jetting velocity resulting from the combustion of the rocket propellant?

Students naturally make such a connection in their minds because they are studying the recoil movement in their Physics course.

If we hypothesize that the gas produced from rocket propellants in the reaction jets outward via a nozzle with a section area of 100cm^2 , how large will the jetting rate against the rocket be then?

Dividing the gas volume under a high temperature condition produced in unit time by the sectional area of the nozzle, we may reckon the relative velocity of gas flow to the rocket with the help of “STELLA”(Figure 17-1and figure 17-2).

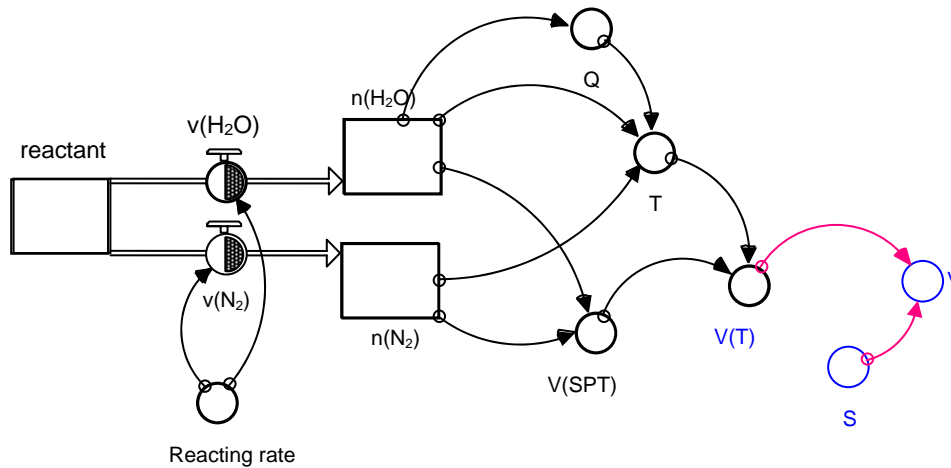


Figure 20

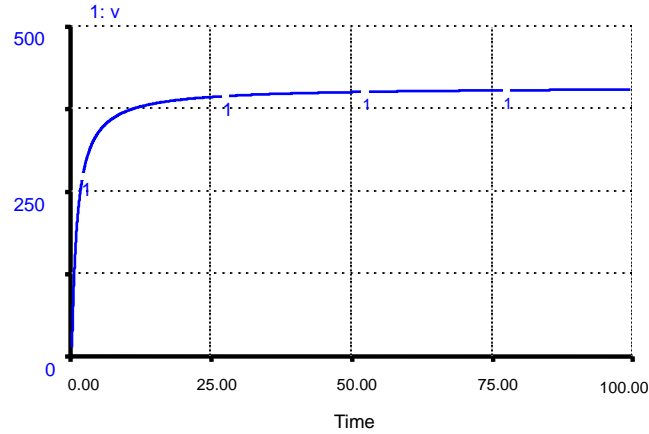


Figure 21

The data above show the gas-jetting velocity at the jet nozzle of 100cm² sectional area is about 40m/sec for a fuel consumption rate of 1.28g/sec. If we can adjust the sectional area of the jet nozzle, or properly change the combustion rate of the fuel, the expected gas-jetting velocity will be achieved.

After school, students carried out simulation experiment on performance between different combinations of propellants on a common multipurpose simulator. The experiment is to compare the differences between acquired propelling force [V (T)], with different propellants of the same mass under the same reaction condition.

To make it easier for investigation, we change the model above into a universally applicable one in which common fuel that produces H₂O, N₂ and CO₂ in combustion is used (Figure 18).

There is no CO₂ produced in the reaction between N₂H₄ and N₂O₄ as the rocket propellant, while corresponding inflow multiplier-CO₂ is set as 0. Similarly, inflow multiplier-CO₂ and inflow multiplier-N₂ may be set as 0 for the investigation of reaction between liquid hydrogen and liquid oxygen.

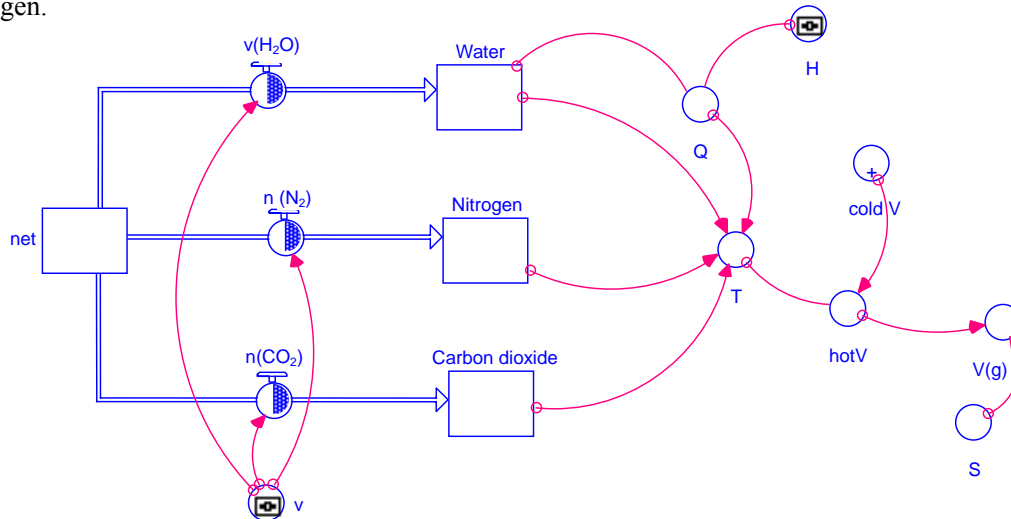
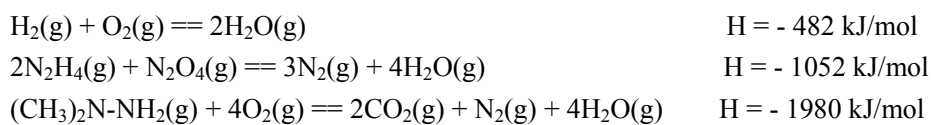
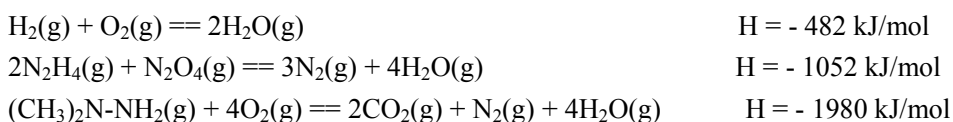


Figure 22



Taking a typical rocket propellant as an example, the thermo chemical reaction in its combustion may be put as follows:



If mass of each fuel taken is 100g, when converted as stoichiometric number, its amount in reaction can be measured in molar, and subsequently taken as the value of “reactant”. For heat released in the production of 1mol water, the inflow multiplier of fuels conversion from the rocket propellants to products are listed in the following table. Propelling force of the rocket is in direct proportion to gas volume V(T). The result of the simulation experiment is as follows:

| Fuel combination | H ₂ , O ₂ | N ₂ H ₄ , N ₂ O ₄ | C ₂ H ₈ N ₂ , O ₂ |
|------------------------------------|---------------------------------|---|---|
| Heat (kJ/1molH ₂ O) | 241 | 263 | 495 |
| Initial amount of material | 2.78 | 0.78 | 0.532 |
| inflow multiplier-H ₂ O | 6 | 12 | 12 |
| inflow multiplier-N ₂ | 0 | 9 | 3 |
| inflow multiplier-CO ₂ | 0 | 0 | 6 |
| V(T) | 1909 | 834 | 508 |

It is not difficult to find that, from the data above, the combination of liquid hydrogen and liquid oxygen still is an optimum option; on the other hand, we anticipated that 1,1-dimethylhydrazine combustion-explosion property is relatively lower because it is a carbon-containing rocket fuel, and this anticipation has been verified in the simulation experiment.

Having extended our research from simple calculation of gas molar volume, after imaging, reasoning, and simulation experiment on the platform provided by STELLA, we unexpectedly find we may so clearly and vividly experience and simulate the research process of the rocket propellants, which was thought to be so mysterious, and complicated in the past that we did not dare to image in the previous teaching activity. Such practice brings great pleasure and excitement to students, so that they can fully enjoy exploration while studying.

What’s more pleasant is that such a series of exploration and reasoning greatly motivates students. Some of them will ask further question: the research starts from combustion-explosion process of black powder, but why does the subsequent investigation move toward rocket propellants? Is there any difference between these two in their respective reaction processes?

Regarding this, the teacher guides students to discovering the difference between a rocket propellant and an explosive after ignition in their reaction modes. A rocket propellant produces gas in a continuous and smooth reaction, which ceaselessly jets outward, and it may thus be assumed that the reaction rate of the rocket propellant is not affected by temperature. In contrast, explosives acts in a limited and airtight container, so the rising of gas temperature will further affect the chemical reaction rate soon after ignition. Thus, using the simulation experiment, corresponding adjustment must be made when investigating the model of an explosive’s performance (Figure 23).

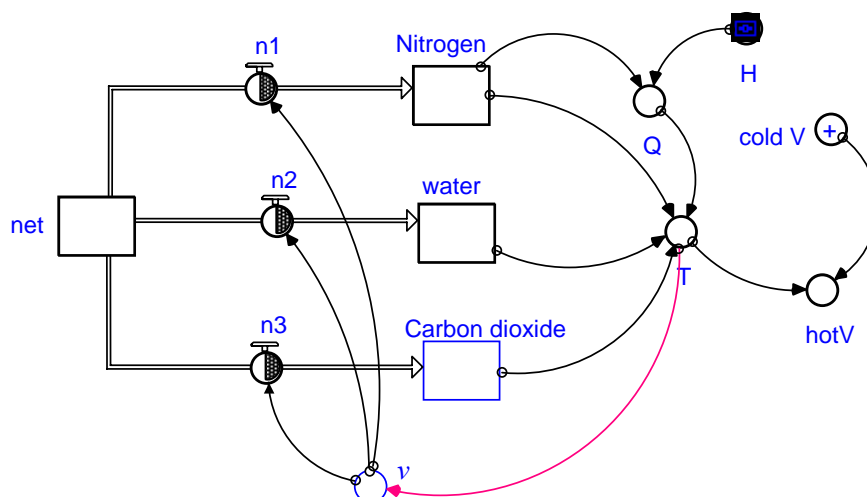


Figure 23

If mass of each fuel taken is 100g, the heat released for per mole of N_2 produced, time required for completion of the reaction, and other parameters are listed as shown in the following table. The result of the simulation experiment is summarized as follows:

| Fuel combination | Heat (kJ/1mol H_2O) | Amount of initial material | V(T) | t (Unit time) |
|---|------------------------|----------------------------|------|---------------|
| Black powder | 572/ N_2 | 0.59 | 559 | 6.48 |
| $C_3H_5N_3O_9$ (Glycerin trinitrate) | 566 | 0.44 | 1139 | 0.80 |

The result shows that the time for the reaction is shortened due to the effect of temperature on the reaction rate during the explosion. It may be anticipated that the impact force will be stronger in a practical explosive process. Moreover, the related data demonstrate again that the brisance of black powder indeed is weaker than that of glycerin trinitrate. Students are glad to know that we human beings have developed many new high-performance explosives by synthesizing new substances, and made brilliant scientific and technical achievements as well.

So they will find the difference between glycerin trinitrate and black powder in their respective composition and structure. Combining that with the studying of organic chemistry, the students understand that the introduction of nitro-group ($-NO_2$) into an organic compound will enlarge the contact area of the combustible with element oxygen in microcosmic structure, and this will be beneficial to rapid initiation of a reaction.

In addition, students also find that, what makes the explosive different from the rocket propellant is their constituent modes: the explosive usually is one-component. That is, its oxidative element and the reductive element coexist in a substance, and this is reasonable because it benefits momentary initiation of the reaction. Students were quite excited for the discovery, and such a process serves as the foundation for the research to improve the explosive's performance.

From systematic point of view, teaching process not only relates to the transfer of knowledge. What is more important, the introduction of the relevant background knowledge

similarly will help students to form a positive attitude toward life in their learning process. Apart from discussing the problems such as those in development of the rocket propellant using the method of system thinking, we shall assist students understanding the influences of explosives invented by Alfred Nobel on human life and the initial intention to set up Nobel Science Award, especially Peace Award, These cases, without doubt, will exert a subtle influence on students in the formation of their individuality.

Postscript

Due to the limit on their cognitive abilities and knowledge structure, for middle school students, the mathematical model established is fairly rough. However, the general rule obtained is reasonable. At the same time, such a way of thinking as well as a method to investigate problems will exert long-term influences on students for their future learning and work, which are the most important and remarkable change that system thinking and system dynamics bring to the teaching of chemistry in high schools.

What impressed the teachers most from the above teaching practice is that learning process of students in high schools period no longer is the simple reception of knowledge. What students experienced is an exploratory process filled with intense emotion, and what they harvested is the knowledge on their surrounding world. They gradually know how to revere and respect the nature and human achievements, and these will encourage them to make similar excellent effort in the future.

It deserves to be mentioned that, in the last years, the target group of our teaching mainly is the students of Grade K10. In the initial stage to use the method of system thinking, the establishment of a model is normally carried out by students under the teachers' instruction. With their deeper understanding of system thinking, students will embark on more models on the development and rules of their surroundings. By that time, we will share more of our ideas with colleagues and demonstrate the progress that students make thanks to such a teaching methodology.

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